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Cosmic Rays—Their History, Source, Nature and Effects

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COSMIC-RAY research is now far enough advanced to provide a true picture of how present-day scientific investigation proceeds. The early work was qualitative in character; theories were developed to explain observations, not to make predictions leading to further experimental work. Recently, ingenious instruments and theoretical and experimental methods of investigation have been developed, and progress has been accelerated. Today there are well-known fruitful methods of investigation, and theory and experiment are working hand in hand.

A calendar of some of the principal events leading to the discovery of cosmic rays will serve as a historical introduction to the subject. The examples were chosen to depict the progress of research in this field, and there was no attempt at completeness.

CALENDAR OF EVENTS LEADING TO THE DISCOVERY OF COSMIC RAYS

1901. H. Geitel and C. T. R. Wilson discovered that a gas in an enclosed vessel is conducting. J. Elster and H. Geitel found that air contains radium emanation.

1903. J. C. McLennan and E. F. Burton, and E. Rutherford and H. L. Cooke, showed that the ionization in a closed vessel is reduced when surrounded by shields free from radioactivity.

H. L. Cooke and C. T. R. Wilson found that bricks and rain water were slightly radioactive.

1905. A. S. Eve found the radioactive content of the air insufficient to explain the ionization of a gas in a closed vessel far out at sea. Norman Campbell discovered that the same gas in vessels made of different materials gave different ionization currents, but that there was some constant residual ionization which he attributed to outside radiation; unfortunately, he later retracted from this position, which we now know to be correct.

1909–1911. A. Gockel made balloon flights to an altitude of 14,000 ft. He used an ionization chamber in which the gas pressure decreased with altitude and did not correct the ionization current for this change of pressure. The uncorrected ionization current decreased more slowly than one expected if the atmosphere were the source of this newly discovered penetrating radiation.

1911–1912. V. F. Hess made ballon flights with an improved type of ionization chamber, and found that the ionization current decreased up to 800 m, and then increased. As a result of his day and night observations, he stated that the sun was not the source of these penetrating rays. Hess was awarded the Nobel prize for his work in cosmic rays.

1913–1914. W. Kohlhörster found the mass absorption coefficient of these penetrating rays to be one-tenth that of the most penetrating γ-rays.

1914–1919. World was made safe for Democracy.

1919–1923. World recuperated.

1923–1924. W. Kohlhörster and G. V. Salis found that the absorption coefficient of these penetrating rays increased with altitude, but did not interpret this as meaning that the rays harden on passing through the atmosphere. R. A. Millikan and R. M. Otis measured the absorption coefficient of these rays on Pike's Peak, and found the coefficient so high that they stated, "this penetrating radiation is of a local nature." We know now that the high absorption coefficient observed by them was due to the transition effect discovered by Hoffman in 1927. A great number of workers believed the source of these rays to be local.

1925. R. A. Millikan and G. M. Cameron lowered their electroscopes in lakes located at different altitudes. It was shown that when ionization current was plotted against

depth, the curves were identical if the amount of matter (water+air) above each electroscope was the same.

1926. Agreement was general that the source of these rays was beyond the atmosphere and that the rays were more penetrating than the hardest rays from radioactive substances. The name *cosmic rays* was adopted by most workers.

Why are we interested in cosmic rays? High energy electrified corpuscles have served the physicist much as the telescope has aided the astronomer or the microscope has served the biologist. Each increase in the specific energy of ionizing particles available to research workers has brought with it a corresponding advance in our knowledge of matter and energy and their interaction. Since the cosmic-ray particles were the most energetic particles known, it is not surprising that this field of investigation immediately attracted many workers.

What are the results? Another particle, the positron, has been discovered. The existence of a new particle, the barytron, with the charge of an electron and a mass intermediate between that of the electron and proton, seems well established. There is good evidence that these latter particles can be produced by the action of non-ionizing radiation on matter at an altitude of 20,000 ft. Perhaps a neutral barytron, the neutretto, is a reality. The interaction of these high energy particles with matter has been, and is being utilized to test theory. Finally, evidence is now accumulating which indicates that the ratio of mutation in drosophilae may be altered by such particles.

Instruments Used in Studying Cosmic Rays

Three instruments are used singly and in combinations to study cosmic rays. These will be described very briefly in order to make the story complete.

The Geiger-Müller counter

The Geiger-Müller (G-M) counter detects the number of electrical particles passing through a given volume. The counter is essentially a diode gas-filled tube, which acts as a unidirectional amplifier. The essential parts are shown in Fig. 1(A). The central electrode W is usually a very small tungsten wire, while the outer electrode T is commonly a thin-walled copper cylinder. The two electrodes are held in position by a glass

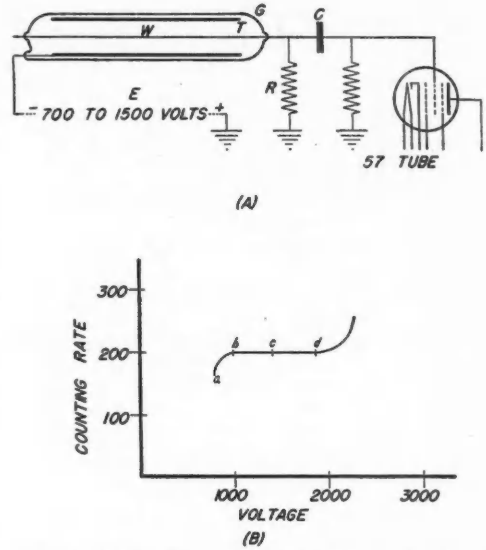


Fig. 1. (A) A G-M counter. (B) Curve showing the counting rate as a function of the applied voltage. [Data from a hydrogen-filled tube made by F. Shonka.]

envelope G. Some gas, such as air, hydrogen, or oxygen and argon, at a pressure of from 5 to 15 cm-of-mercury, fills the counter. In the standard resistance coupled circuit, the outer cylinder is connected to the negative terminal of a source of high potential E, while the positive terminal is connected through a high resistance R (10^8 to 10^{10} ohms) to the central wire. When ionizing corpuscles enter the G-M counter, the gas is ionized and ions and free electrons are produced. With proper adjustment of voltage on the counter tube and pressure of the gas within the tube, the free electrons (not the ions) acquire sufficient energy between collision to produce more ions and electrons by impact. This process of ion and electron magnification continues until the difference in potential between the central wire and cylinder falls below that necessary for electrons to produce ionization by collision. The discharge then terminates and the tube recovers by the charge leaking off through the high resistance. The time of recovery depends on the product RC as well as the G-M counter and varies from 10^{-1} to 10^{-5} sec. Thus, the passage of one ionizing particle through the tube momentarily places on the central wire a relatively large charge of negative electricity, which in turn impresses a

potential on the control grid of a vacuum tube.

If the counter is exposed to a constant source of radiation while the voltage E is varied, and the number of electrical pulses per second is plotted against the applied voltage, the curve shown in Fig. 1(B) results. The threshold voltage a is the lowest voltage at which the counter will detect the passage of ionizing particles. Since the counting rate is practically independent of the applied voltage between b and d—the voltage plateau of the curve—the tube is operated at some intermediate voltage such as c. Some of the counts are produced by local radioactive substances near or even within the tube and, when a single tube is used, the residual count and the efficiency of the counter must be determined.[1]

It has become a common practice to use the geometrical arrangement of three or more counters shown in Fig. 2(A), which is known as a G-M telescope. It will be seen from what follows that such an arrangement is insensitive to local radiation of the γ-type and, with modern circuits, practically insensitive to low energy β-particles of local origin.

The pulses from these counters are fed into a recording system that responds only when all counters are actuated simultaneously. Thus, it will respond to those rays moving in directions included within the angle POP and to the simultaneous passage of different ionizing corpuscles, such as a, b, and c. If the counters are placed out of line, they will not be actuated by the passage of one particle through all counters, and the number of spurious counts caused by particles such as a, b, c, will be the same; hence, one can determine the number of such spurious coincidences. The number of these so-called, accidental coincidences may be rendered insignificant by using a large number of counters. However, this lowers the detecting efficiency of such a telescope, because the efficiency of an n-fold telescope is E^n, where E is the efficiency of an individual counter. This efficiency E decreases with the number of particles passing through a counter, because the counter is insensitive for a time t after the passage of an ionizing particle; in fact, the efficiency of a single counter is given by the equation

$$E=(1-Nt), \tag{1}$$

where N is the number of particles passing through the G-M counter. Until very recently, the recovery time of recording circuits has been much greater than that of the G-M cylinder itself. The over-all efficiency of the G-M tube and recording circuit may be determined by the following procedure. One disconnects, but leaves in position, counter *2* and determines the two-fold coincidences in counters *1* and *3*. Then, *2* is connected in the circuit and triple coincidences are recorded. If counter *2* has an efficiency of 100 percent, and corrections are made for accidental coincidences in each case, the number of triple coincidences T would equal the number of double coincidences D. If $T/D=0.90$, the efficiency of counter *2* is 90 percent. The over-all efficiency of a G-M telescope consisting of four counters with efficiencies of 90 percent each would be 0.90^4 or about 66 percent. The recent circuits of Neher and Pickering, and Neher and Harper have greatly increased the efficiency until it is now possible to use a sufficient number of counters to reduce spurious counts to an insignificant number without materially lowering the efficiency. The efficiency of these counters is usually as high as 98 percent for electrical particles, but less than 1 percent for quanta of γ-radiation. Thus, when one uses a G-M telescope he does not need to shield it against local γ-rays or soft

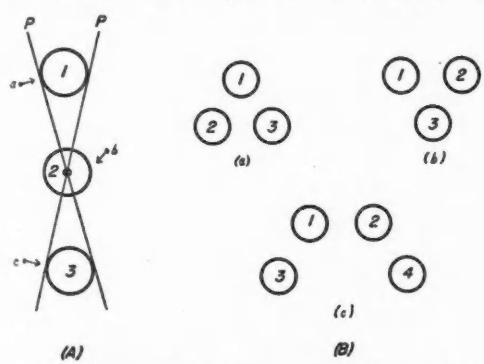


FIG. 2. (A) Geometrical arrangement of counters in a G-M telescope; it will respond to single ionizing particles whose path is included in angle POP. (B) In arrangements (a), (b), (c), two or more particles, each moving in a straight line, are required to produce simultaneous impulses in all three counters.

[1] An excellent account of G-M counters and recording circuits is given in J. Strong's *Procedures in Experimental Physics* (Prentice-Hall, 1938).

corpuscular radiation which will not penetrate several counters. But a G-M telescope gives the intensity of radiation for certain limited directions, and several directions must be used to compute the total intensity.

A set of G-M counters can be arranged out of line as in Fig. 2(B). Here two or more particles are required to set off the recording mechanism. These arrangements are used in the study of cosmic-ray showers. In all cases, it should be remembered that a G-M counter records the number of ionizing particles passing through a given volume, not the number of ions formed within this volume.

Ionization chamber

Another device which has been in use for a long time is the combination of an ionization chamber and an electrometer shown schematically in Fig. 3. The essential parts are a central electrode R, a metal chamber or bomb B, a battery V, and some type of electrometer E, such as a Lindemann or a Dersham electrometer. The chamber is filled with some gas such as argon at a pressure of from 10 to 70A. When the key K is closed, the ions produced in B will migrate toward R or B, depending on the sign

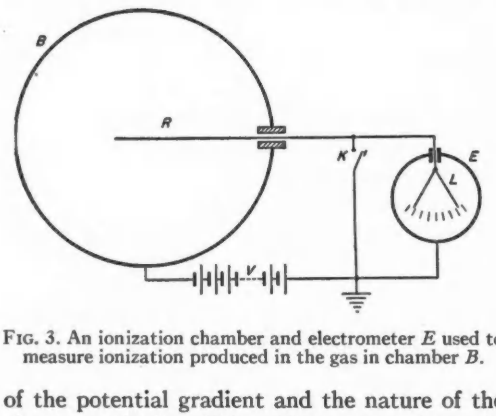


FIG. 3. An ionization chamber and electrometer E used to measure ionization produced in the gas in chamber B.

of the potential gradient and the nature of the charge on the ion. When K is opened, ions will flow to L. If the chamber voltage is sufficient to sweep the ions across as fast as they are produced, the rate at which L collects a charge is a measure of the rate at which ions are being formed within the chamber. This, in turn, is a measure of the total ionizing radiation being absorbed within the chamber. If C is the capacitance of the collecting system and Q is the charge on the collecting system,

$$Q=Cv, \tag{2}$$

$$ne=dQ/dt=C(dv/dt), \tag{3}$$

where n is the number of ions captured per second and e is the charge on each ion. Hence, for absolute measurements C and dv/dt must be determined. By means of a potentiometer, varying potentials are placed on L and the resulting deflections of electrometer E are observed, from which a voltage sensitivity curve is constructed. By the aid of this curve the potential of the collecting system for each deflection may be determined. The relationship between voltage and deflection is linear over the range used; hence, $dv/dt=\Delta v/\Delta t$. Δt is determined with a stop watch. To determine C, a condenser of known capacitance C_1 is connected in parallel with the collecting system and a constant source of ionization is used. The corresponding times, Δt and Δt_1, for the same Δv are noted in each case. In the first case we have

$$ne=C\Delta v/\Delta t,$$

while in the second case,

$$ne=(C+C_1)\Delta v/\Delta t_1,$$

where C_1 is the capacitance of the condenser connected in parallel. From these last two equations one obtains the relation,

$$C=C_1\Delta t/(\Delta t_1-\Delta t), \tag{4}$$

from which C is computed. In contradistinction to the G-M counter, it should be noted that an ionization chamber measures the total number of ions formed within the chamber, not the number of ionizing particles passing through it. Since it is sensitive to γ-rays, when used to measure cosmic rays it is shielded by outer layers of lead or other heavy material and inner layers of some nonradioactive material such as copper. As long as one maintains saturation voltage, the efficiency of detecting ions is not a function of the intensity of ionization.

The ionization produced is found to increase as the temperature of the gas within the chamber is increased. To compensate for changes in temperature, Compton, Wollan and Bennett place a small ionization chamber within the larger

chamber. The respective chamber voltages are reversed so that one supplies positive current and the other negative current to the electrometer. The smaller chamber contains some radioactive source of ionization, while the current from the larger is due to cosmic radiation. The respective ionization currents from the two chambers are adjusted to annul each other, and the electrometer reading is traced on a moving film. Since both chambers are subject to the same temperature changes, this method materially reduces any variations due to temperature. Such a combination is used to study sudden and abrupt changes of ionization in the large bomb, as well as to record cosmic-ray intensity continuously.

The expansion chamber

C. T. R. Wilson is reported to have got the idea of the expansion chamber from watching clouds form over mountains when the moist air hits the side of the mountain and is suddenly lifted with consequent expansion and cooling. This observation of adiabatic expansion has given the cosmic-ray workers one of their most useful tools. The Wilson cloud chamber is so well known that only the briefest description of the working parts, along with the adaptations for cosmic-ray work, will be considered.

The essential parts are shown in Fig. 4. A movable piston P is in cylinder C. The space within the cylinder is kept saturated. A potential which sweeps the space free of ions is applied to the electrodes R and P. When the piston is suddenly moved outward, the air expands and cools, and water condenses on any ions formed within the chamber. If these ions are produced by a high energy charged corpuscle, a track is formed which may be photographed simultaneously by two cameras, K, K, placed perpendicular to each other, thus providing a stereoptic view of the path. It is of interest to note that one gets a photograph of the path of a particle which is too small to be seen, and which is going too fast to be seen if it were large enough. If the chamber is expanded at random and photographs are taken at each expansion, a true sample of cosmic-ray events will be obtained. However, this results in relatively few pictures of the desired phenomena. Blackett and Occhialini devised a method by which the expansion of cloud chambers could be controlled by G-M counters. If G-M counters are placed above and below an expansion chamber, their pulses may be fed into a circuit which will cause an expansion each time an ionizing particle passes through a top and bottom counter. These counters will also control the mechanism by which the cameras are automatically operated. The action of the camera may be delayed by suitably designed

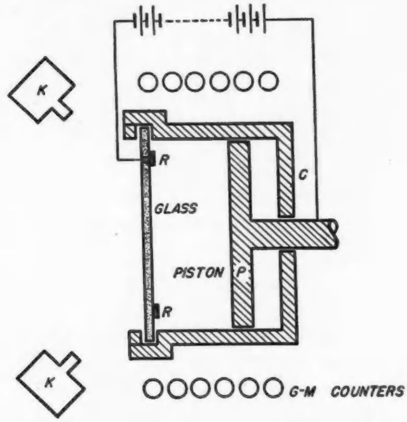


FIG. 4. A Wilson expansion chamber. The paths of ionizing particles through the chamber are photographed by the two cameras. The G-M counters above and below the chamber are used to release the mechanism that withdraws the piston and operates the cameras. This action may be initiated by an ionizing particle passing simultaneously through any predetermined combination of top and bottom counters.

circuits. If all the counters above the chamber are connected in parallel and those below likewise connected, the resultant G-M counter system would detect almost any ionizing particle traversing the chamber. If one is interested in single tracks alone, one counter above and one below may be used as a G-M telescope. If photographs of two or more particles are desired, then several counters below are so connected that each must be traversed by an ionizing particle simultaneously with one or more of the top counters. Thus, the type of phenomena one wishes to photograph is determined, but it should be remembered that such a mechanism no longer gives a true sample of random cosmic-ray events.

Before discussing the type of information we can secure with an expansion chamber, it may be well to list the equations which are commonly

used. If a charged particle of rest mass m, in grams, and of charge e, in emu, moves perpendicularly to a magnetic field of strength H, in gauss, the total energy E, in ergs, is

$$E = mc^2(1-\beta^2)^{-\frac{1}{2}}, \tag{5}$$

where $\beta = v/c$, while the kinetic energy T, in ergs, is

$$T = E - mc^2. \tag{6}$$

If the radius of curvature of the path of the particle is ρ, in centimeters,

$$He = (mv/\rho)(1-\beta^2)^{-\frac{1}{2}}, \tag{7}$$

$$\beta = H\rho[(mc/e)^2 + (H\rho)^2]^{-\frac{1}{2}}, \tag{8}$$

$$E = H\rho ec^2/v = ec[(mc/e)^2 + (H\rho)^2]^{\frac{1}{2}}. \tag{9}$$

For most cosmic-ray electrons, mc/e is small compared to $H\rho$ and the approximate relation

$$E = eH\rho c \text{ ergs} = 300H\rho \text{ ev} \tag{10}$$

is used. For $H\rho > 1.3\times 10^4$ gauss cm, Eq. (10) gives the energy for an electron within 1 percent. The energy of protons, greater than 3×10^3 Mev can be determined by this formula with an error of less than 6 percent. Thus, the energy of most cosmic-ray particles may be assumed to be proportional to $H\rho$. Unless it is known that $(mc/e)^2 \ll (H\rho)^2$, it is necessary to know both e and m before the energy can be determined from the curvature of the path in a known magnetic field. It may be necessary to determine e and m by trial and error, checking the results by range and specific ionization (ions formed per centimeter of path).

Observations on particles from natural and artificial radioactive substances show that the rate of loss of energy and the specific ionization are proportional to e^2/v^2, while the range is proportional to v^3. However, specific ionization depends so little on m that the discovery of the positron was delayed because its track was mistaken for that of a proton. On rare occasions, a direct collision is observed between a known and an unknown particle from which information can be obtained regarding the mass and velocity of the unknown particle. Photographs illustrating some of these points appear in Fig. 5.

By using a vertical expansion chamber containing a strip of lead within a strong magnetic field normal to the chamber, one can see the paths of cosmic ionizing particles and can determine their direction, the sign of their charge, their energy, the loss of energy in passing through matter, and the number of ions produced per centimeter of path; and, under favorable conditions, one can also determine the mass and charge of the ionizing particle.

What is the Source of Cosmic Rays?

Now let us turn to cosmic rays themselves and see what has been found out regarding them by means of the instruments we have described.

The calendar of historical events in the discovery of cosmic rays indicates clearly how long it required to show that these penetrating rays were of cosmic origin. They were first attributed to the radioactivity of the earth. To test this point, observers went farther from the earth by going far out to sea, by climbing towers and finally by making balloon flights. When an increase of intensity in these rays with altitude was observed, the opposite tactics were employed. Men took their instruments farther away from the outside universe by placing more absorbing material between their instruments and the zenith. This was done by boring holes in icebergs and by sending instruments deep down into snow-fed lakes. Finally, it was definitely shown that cosmic-ray intensity was completely determined by the material between the instrument and outer space. This absorbing material was made up of the atmosphere and the iceberg, or the water in the snow-fed lakes and any shields placed around the instrument.

But from what point or points in the cosmos did these penetrating rays come? Could it be the stars, cold interstellar space, expanding novae, or were they generated by the large potentials set up during thunderstorms?

As early as 1911, Hess said the sun, our nearest star, was not the source of these rays. Nevertheless, the possibility of other stars being the source has been carefully checked. By placing an ionization chamber in a narrow gorge, such as the Royal Gorge, or in a small but very deep lake, the cosmic-ray meter receives rays from a narrow strip of sky directly overhead. If the source is the stars, the intensity of cosmic rays, as recorded by these instruments, should be much greater

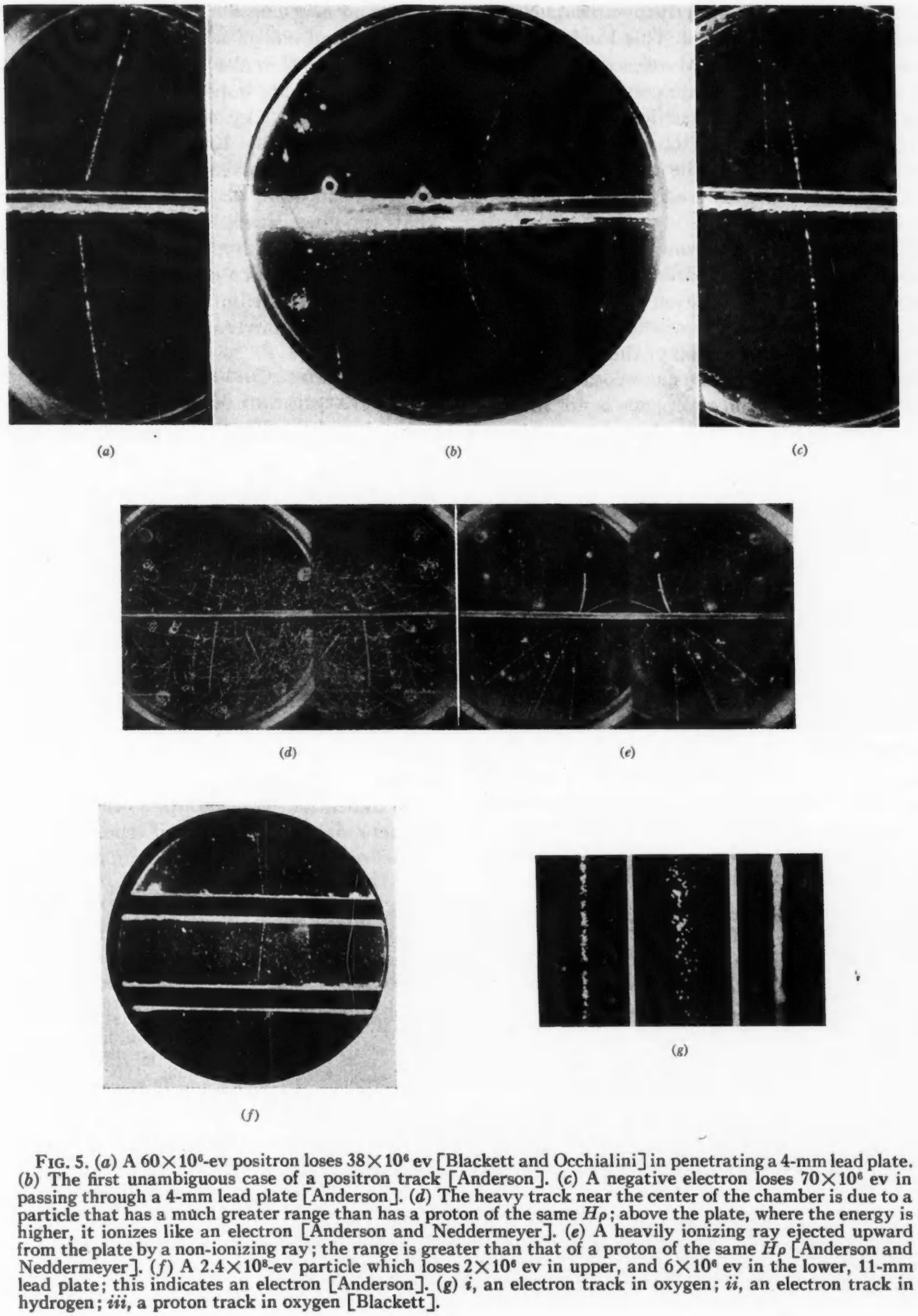


FIG. 5. (*a*) A 60×10^6-ev positron loses 38×10^6 ev [Blackett and Occhialini] in penetrating a 4-mm lead plate. (*b*) The first unambiguous case of a positron track [Anderson]. (*c*) A negative electron loses 70×10^6 ev in passing through a 4-mm lead plate [Anderson]. (*d*) The heavy track near the center of the chamber is due to a particle that has a much greater range than has a proton of the same $H\rho$; above the plate, where the energy is higher, it ionizes like an electron [Anderson and Neddermeyer]. (*e*) A heavily ionizing ray ejected upward from the plate by a non-ionizing ray; the range is greater than that of a proton of the same $H\rho$ [Anderson and Neddermeyer]. (*f*) A 2.4×10^8-ev particle which loses 2×10^6 ev in upper, and 6×10^6 ev in the lower, 11-mm lead plate; this indicates an electron [Anderson]. (*g*) *i*, an electron track in oxygen; *ii*, an electron track in hydrogen; *iii*, a proton track in oxygen [Blackett].

when our galaxy is directly overhead. No such change has been observed. This has been further checked by using a G-M telescope to measure the intensity of cosmic rays coming from the sun, our galaxy, and other portions of the sky. So long as one keeps other factors constant, such as the amount of air in the absorbing layer, all portions of the sky send us the same number of cosmic rays.

Do these rays come from beyond our galaxy? Our whole galaxy is drifting through space toward Cepheus, declination 47°N, right ascension $20^h\ 55^m$ at a speed of 300 km/sec. If the source is beyond our galaxy, then the northern hemisphere should receive more cosmic rays than the southern, and since Cepheus is not in a true northerly direction, there should be a diurnal variation. If these rays are γ-rays, there should be a Doppler effect, while if they are particles, the number incident on the northern hemisphere should exceed the number reaching the southern hemisphere. Compton and Getting calculated the magnitude and the phase of this effect, and early data indicated that the earth was moving with respect to the source of cosmic rays. The phase and amplitude were in accord with the theoretical predictions; but Compton said he would know more about it after 10 years of data had been accumulated. The most recent analysis by Compton and Gill of the more detailed and extensive data now available contradicts the earlier results, for there seems to be no appreciable motion of the earth with respect to the source of cosmic rays, and hence cosmic rays appear not to come from beyond our galaxy.

When the Hercules Nova appeared in 1935, scientific workers hoped to test the hypothesis of Baada and Zwicky that cosmic rays come from supernovae. While Kohlhörster believes there was a 2-percent increase during this event, the results from other observers were so conflicting that we must await the appearance of other novae before this hypothesis can be tested. If novae are the source of cosmic rays, they must be uniformly distributed in celestial space and appear at a uniform rate.

Variation of Cosmic-Ray Intensity with Geographic and Meteorologic Factors

Cosmic-ray intensity is a function of altitude. The number of ions per unit time formed in a given volume of gas under standard conditions at 14,000 ft is 5 times what it is at sea level. At 50,000 ft, the intensity is more than 200 times what it is at sea level. As will be shown in a later section, the cosmic-ray intensity decreases as one goes from 50° N magnetic latitude toward the equator. The intensity varies inversely with the barometric pressure, this being a pure absorption phenomenon. No significant variation with the type of weather or the seasons has been definitely established, nor is there any regular significant diurnal variation. There seems to be some indication of a variation with the earth's magnetic field, though this, if true, is slight.

The results from the continuous cosmic-ray

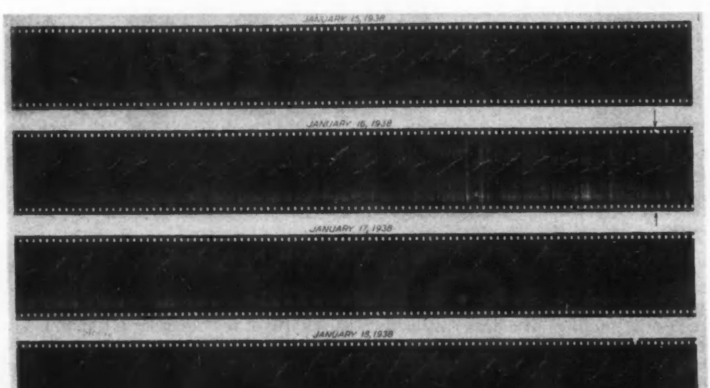


FIG. 6. Cosmic-ray records, Huancayo, Peru, showing effects of a magnetic storm which began at $22^h\!.7$ GMT, Jan. 16, 1938. The records were made with the self-recording type of ionization-chamber cosmic-ray meter. The variation of the slope of the line indicates the variation in cosmic-ray intensity. Note how the slope starts to increase at the point indicated by the arrows. An increase in slope means a decrease in cosmic-ray intensity.

work recording meters at Cheltenham (U. S.), Teoloyucan (Mexico), Christchurch (New Zealand), and Huancayo (Peru) indicate that there are changes in cosmic-ray intensities and that such changes are world wide. These world-wide changes increase rapidly with altitude for stations of the same latitude. At high altitudes, the magnitude of these world-wide changes increases between geomagnetic latitudes 0° and 30° N, but shows little increase between 30° N and 47° N. There is also a 12-month cycle which cannot be explained on the basis of a magnetic effect due to the sun. It is suggested by Forbush that these changes are probably due to the mechanism causing worldwide decrease in cosmic-ray intensity during some magnetic storms. A tracing showing the change in intensity during a magnetic storm is shown in Fig. 6. Since this effect is observed at all stations and coincides so nicely with the time of the magnetic storm, it would seem there is no doubt that the two are connected. Yet there has been a magnetic storm when no such effects were observed. It is for this reason that the Carnegie Institution of Washington, D. C., keeps meters recording cosmic data at the station previously mentioned. Only those trained in science can visualize the possible value of such findings.

What are Cosmic Rays?

From the beginning, it was known that cosmic rays ionize a gas. Both γ-rays and charged particles produce this effect. How then was one to determine the nature of this penetrating radiation? Could the penetrating power be the means of determining the nature of the rays? γ-rays were known to be about 100 times as penetrating as β-particles of the same energy. At that time physicists were not thinking in terms of millions of electron volts, much less talking casually about several billion electron-volts. Hence, when in 1927 Millikan and Cameron found that these rays penetrated water equivalent to 2 m of lead, it was not surprising that Millikan should have considered them to be ultra-γ-rays. His theory, which pictured these rays as being generated in cold interstellar space, when atoms were born, stirred the imagination and led to an abundance of fruitful experimentation.

Regener, using an ionization chamber, has detected cosmic rays 230 m below the surface of water; while Kohlhörster, Wilson, Morgan and Nielsen have detected them at a depth equivalent to more than 500 m of water, or about 12 m of lead. As previously pointed out, a G-M counter telescope is almost always actuated by electrically charged corpuscles, practically never by photons. Street and Stevenson have shown this to be the case with cosmic rays and have detected particles after the latter have penetrated a meter of lead. Some of the intensity measurements at great depths have been made with G-M counter telescopes. Current experiments and modern theory both present strong evidence that, at high energies, penetrating power is not a criterion for differentiating between photons and electrons.

We should like to be able to answer two questions: What is the nature of the rays we measure in the atmosphere? What is their nature before they reach the atmosphere? If γ-rays were incident on the top of our atmosphere, they would produce electrons and positrons, perhaps barytrons; if charged particles enter the atmosphere, their interactions with the air molecules would produce high frequency photons. Thus, the question resolves itself into the two parts just mentioned. Can we not determine their nature with the magnetic field, as is done in the case of α-particles, β-particles, and γ-rays from radioactive substances? In the case of natural radioactive rays, a strong field is used and the separation is effected in a short distance. We may use the earth's magnetic field, for, though it is weak, it extends to great distances from the earth; in fact, the field strength at 15,000 mi from the earth's surface is 1 percent of the value at the surface.

Let us see what effects this magnetic field will have on the paths of electrically charged particles coming towards the earth. A rough idea of the qualitative effects may be obtained by considering the earth's field as that due to a bar magnet of magnetic moment 8.2×10^{25} emu cm. The external field due to this magnet is directed from 72° S, 155° E, toward 79° N, 80° W. From Eq. (9), where v is the component of velocity perpendicular to the field, one can predict the following results.

Since vertical rays reaching the earth at the magnetic poles will be moving parallel to the lines of magnetic force, they will not be deviated by the earth's magnetic field, and, so far as the magnetic field is concerned, rays of all energies should reach the earth at the polar regions. However, the atmosphere will absorb some of the softer rays, and one should expect an increase in intensity and a general softening of the rays with increasing altitude. Now, consider the rays at the magnetic equator. All rays of the same type and energy moving parallel to the equatorial plane will be moving perpendicularly to the magnetic field and, hence, will experience the same deflection. As an example, consider a charged particle 4000 mi above the earth, moving along a segment of its orbit parallel to a normal to the earth's surface. It would not reach the earth if the radius of curvature of its arc were equal to the radius of the earth. In Fig. 7(A), rays of specific energy E_θ will be able to reach point O on the earth if they move in a direction included between OA' and OA. If the energy is higher, the angle θ is larger. There is a definite angular opening in this plane for each energy. Now consider equatorial rays moving in the plane of a magnetic meridian. Their deflection depends on the component of velocity perpendicular to the magnetic field; hence, horizontal rays in this plane would not be deflected at all. The deflection would increase as the direction of the ray approached that of the normal to the surface of the earth. Further, if a

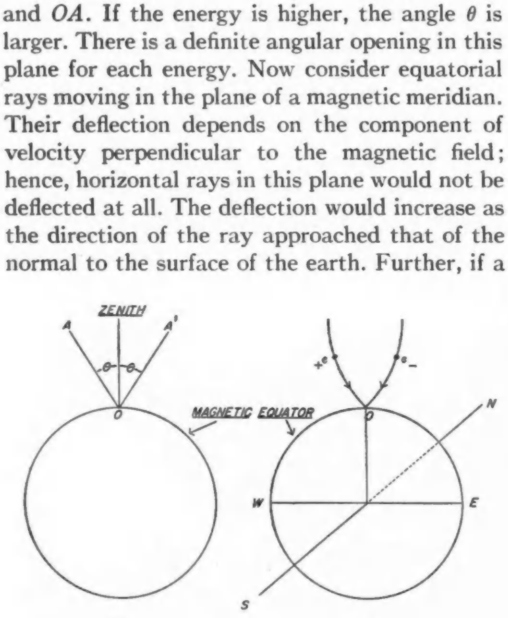


FIG. 7. (A) represents the angle that includes the possible directions in which a cosmic ray of specific energy might move and be able to penetrate the earth's magnetic field and reach the equator. (B) indicates the respective paths taken by positive and negative particles at the equator.

positive ray is moving toward the earth, it will be bent toward the east, while the negative will be bent toward the west, as illustrated in Fig. 7(B). Thus, if these cosmic rays are charged corpuscles, the following predictions may be made.

East-west asymmetry.—If the positives exceed the negatives in number, a G-M telescope would detect a greater number of rays when pointed at a given angle west of the zenith than when rotated through 180° about a vertical axis. This asymmetry should be greatest at magnetic latitude 0°, because the horizontal component of the earth's field is greatest there. Also, there is a general hardening as cosmic rays

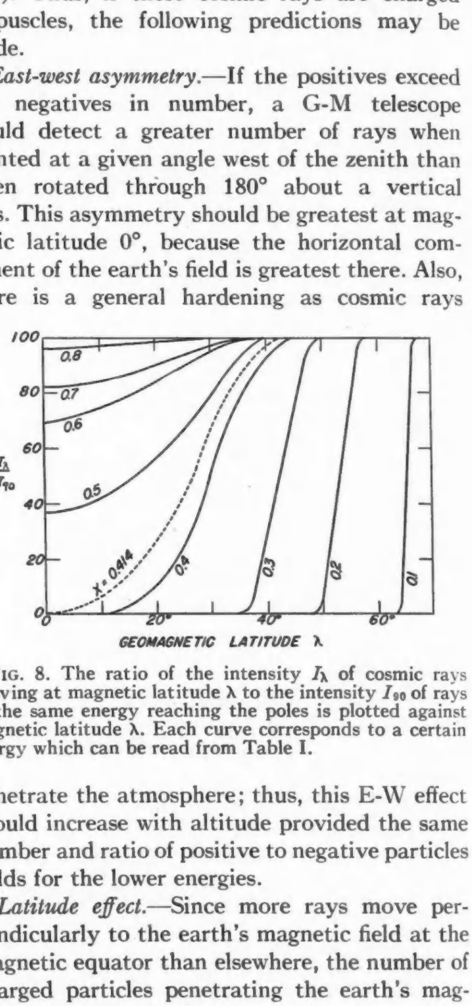


FIG. 8. The ratio of the intensity I_λ of cosmic rays arriving at magnetic latitude λ to the intensity I_{90} of rays of the same energy reaching the poles is plotted against magnetic latitude λ. Each curve corresponds to a certain energy which can be read from Table I.

penetrate the atmosphere; thus, this E-W effect should increase with altitude provided the same number and ratio of positive to negative particles holds for the lower energies.

Latitude effect.—Since more rays move perpendicularly to the earth's magnetic field at the magnetic equator than elsewhere, the number of charged particles penetrating the earth's magnetic field should be lowest in this region. Furthermore, the rays reaching the earth's surface at the equator should be more penetrating than those arriving elsewhere and the variation of penetrating power with altitude should be more marked for high latitudes. All these effects should vary with geomagnetic latitude rather than with geographic latitude.

Le Maitre and Vallarta have presented a solution of the effect of the earth's magnetic

TABLE I. *Equivalent electron voltages for various values of X.*

X	Electrons (10^{10} v)	Protons (10^{10} v)	α-particles (10^{10} v)
0.1	0.0596	0.01722	0.01842
0.2	0.238	0.1618	0.2308
0.3	0.536	0.449	0.760
0.4	0.954	0.861	1.564
0.5	1.490	1.397	2.625
0.6	2.145	2.050	3.928
0.7	2.920	2.823	5.46
0.8	3.821	3.719	7.25
0.9	4.830	4.729	9.27
1.0	5.96	5.85	11.52

field on charged corpuscles moving in this field. Their results are shown in Fig. 8, where curves for certain values of X are plotted; X is defined by the equation

$$X = r(mv/eM)^{\frac{1}{2}},$$

where M is the magnetic moment of the earth, r is the radius of the earth, and m, v, and e are, respectively, the relativity mass, speed, and charge of the particle. As Jauncey[2] points out, the kinetic energy of electrons is given very approximately by the relation K.E. $= 6.0\times 10^4 X^2$ Mev. G. F. Hull[3] gives values of energies for electrons, protons, and α-particles corresponding to values of X; these are shown in Table I.

Let us consider the three curves $X = 0.1$, 0.414, and 0.6, respectively. From the first, we see that electrons of energy 0.0596×10^{10} v, or protons of 0.01722×10^{10} v, or α-particles of 0.01842×10^{10} v will arrive at λ greater than 63° but none will arrive between 63° and the magnetic equator. The curve for $X = 0.414$ is chosen because it represents the charged particles of the lowest energy that can reach the equator and, for the electron, represents an energy of about 10^4 Mev. We see from the curve $X = 0.6$ that about 0.7 as many electrons of energy 2.145×10^{10} v reach the earth at the equator as at $\lambda = 35.0$. To determine the intensity for any latitude, one must sum up the intensities for all values of X which can penetrate the earth's magnetic field at that latitude.

What do actual experiments show? Let us consider the east-west asymmetry. The experimental procedure is as follows. In Fig. 9, the telescope is mounted so it can be rotated about a vertical axis OZ. Counts are taken for some zenith angle θ, when the long axes of the G-M counters of the telescope lie in a N-S plane. The telescope is then rotated through an angle of 180° and counts are again recorded. If E is the number of counts when the angle is east of the zenith and W the corresponding number of counts for a west zenith angle, the *asymmetry* is customarily defined by the equation,

$$2[(W-E)/(W+E)](100) = \text{percent asymmetry}.$$

Johnson, Alvarez, Stevenson, Clay and Korff have made extensive measurements of this effect. No asymmetry has been found at latitudes greater than 50°. On Mt. Evans, Colorado, altitude 14,250 ft, W exceeds E by 2 percent. At the equator, this excess is as much as 10 percent. Also, at the equator, Johnson found the asymmetries for altitudes 0, 3500, and 4500 m which are presented in Table II. We see that the experimental results are in complete qualitative agreement with the theoretical predictions made on the assumption that cosmic rays are charged particles and, further, that among the hard rays reaching the magnetic equator, there are 10 percent more positives than negatives.

In the case of the latitude effect, there is a striking agreement with the predictions of theory. In 1927, Clay, Berlange and Woltjer in sailings between Amsterdam and Batavia, found the sea-

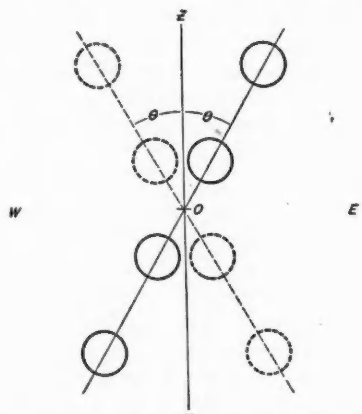


FIG. 9. A G-M telescope mounted to measure the intensity at equal angles θ, east and west of the zenith.

[2] G. E. M. Jauncey, *Modern Physics* (Van Nostrand, 1937), p. 486.

[3] G. F. Hull, *Elementary Survey of Modern Physics* (Macmillan, 1935), p. 293. Table I is reproduced by courtesy of Professor Hull.

level intensity of cosmic rays to be 20 percent less at the equator than at 45° N. Acceptance of these findings was delayed because Millikan had found no such difference between magnetic latitudes 41° and 70°. In 1931, A. H. Compton organized a world survey of cosmic rays, and findings of his confirmed the work of Clay and associates. More recently, Millikan and his co-workers have investigated the latitude effect at high altitudes by means of airplane flights, and Clay has used pilot balloons to study the same phenomenon. The results of these investigations are shown in Fig. 10(A) from which it is seen that the relative decrease in intensity between $\lambda=50°$ and $\lambda=0°$ at altitude 4360 m is roughly 2.5 times what it is at sea level. After correcting the data for the temperature effect, Compton and Turner found the cosmic-ray intensity at sea level, $\lambda=0°$, to be 90 percent of the sea level intensity at $\lambda=50°$. Thus, at 4360 m the effect is about 25 percent, which means that at least one-fourth of the cosmic radiation at this altitude must be made up of charged particles. At an altitude of 15 km, Clay's data on the latitude effect indicated that 96 percent of the cosmic radiation reaching our atmosphere consists of charged particles. However, much more data must be obtained before this percentage can be determined accurately. The data taken by Clay, shown in Fig. 10(B), indicate that the equatorial cosmic rays are more penetrating than the polar rays.

TABLE II. *Percentages of W−E asymmetry at altitudes indicated.*

ZENITH ANGLE	0	3500 (m)	4500 (m)
15°	6	6.5	7.0
30°	8	10	13
45°	10	13	14

What are these particles: electrons, protons, barytrons, α-particles? In Fig. 11, the vertical intensity of cosmic rays is shown as a function of altitude for several latitudes. It will be noticed that there is a maximum at each latitude, while at 52° there is an inflection point. Each charged particle of a given energy has a definite range in a gas and ionizes a little more copiously near the end of its path. A. H. Compton analyzed these curves on this basis and concluded that the primary rays probably are composed of α-particles, negatrons, positrons, and protons. This conclusion has been modified by further work. Just recently Schein and Wilson, working with Compton, have obtained experimental evidence that at 20,000 ft, non-ionizing radiation is producing penetrating cosmic-ray particles when it reacts with matter. The apparatus is shown in Fig. 12. When the 2.2-cm lead block is in position *A*, ionizing particles liberated from it by non-ionizing rays which have passed through counter *1* will not trip the recording mechanism. When the lead scatterer is placed in position *B*, it will absorb the same number of particles, but any ionizing particles produced in this block and passing through all the counters will operate the recording mechanism. The ratio of counts per minute with the lead in position *B* to that with the lead in position *A* is unity for altitudes below 20,000 ft. At 25,000 ft it is found that two ionizing particles per minute were ejected in a forward direction from this lead scattering block. It is interesting to note that 25,000 ft is about the altitude at which a hump occurs in the curve for cosmic-ray intensity *vs* altitude at latitude 52°. These penetrating rays might be protons or barytrons but not electrons. When augmented by more data obtained by airplane flights, these data will undoubtedly throw new light on the nature of the cosmic rays entering the atmosphere. At present, the experimental evidence indicates quite definitely that:

1. The large percentage of cosmic rays entering our atmosphere are charged particles.
2. There is a 10-percent excess of positives at the equator.

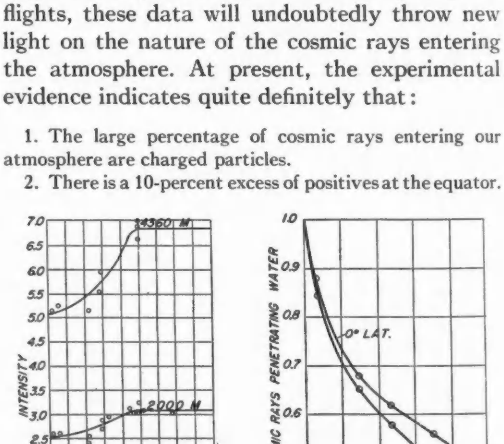


FIG. 10. (A) Variation of cosmic-ray intensity with latitude for altitudes 0, 2000, and 4360 m. (B) This curve shows that the equatorial cosmic rays are more penetrating than those at 45° N latitude.

3. The minimum energy of these rays reaching the equator must be 10^{10} v if electrons, 0.94×10^{10} v if protons, or 1.7×10^{10} v if α-particles.

4. Theoretical analysis of intensity *vs* altitude curves at various latitudes, as well as direct cloud-chamber observations, indicate that protons and α-particles are not present in any appreciable numbers in the cosmic rays incident on the atmosphere. Hence most of the cosmic rays are electrons of both signs, with the positives predominating.

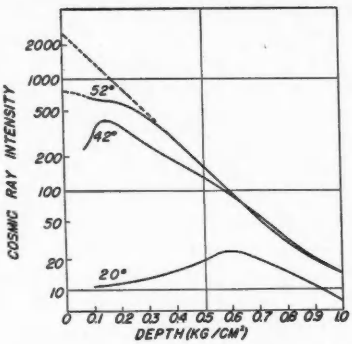


FIG. 11. Variation of cosmic-ray intensity with altitude for latitudes 20°, 42°, and 52° N.

Absorption of Cosmic Rays

It has already been pointed out that cosmic rays are more penetrating than the highest frequency γ-rays. The penetration of these rays may be determined by placing thick shields around an ionization chamber or a single G-M counter. This may be accomplished by sinking the instruments in deep snow-fed lakes. All experiments show that there is a soft component and a very penetrating component of cosmic rays. Sixty percent of the cosmic radiation is absorbed by a few meters of water at an elevation of 14,000 ft, lat. 50° N. From underwater measurements, Millikan states that the total cosmic-ray curve may be built up of components having linear absorption coefficients of $\mu = 0.5$, 0.07, and 0.015 per meter of water, respectively. While there is no unique solution to the problem, this gives a good idea of the range of energies found in the cosmic-ray spectrum. Another way to measure the absorption coefficient is to place the absorbing material between the G-M counters of a cosmic-ray telescope. Counts taken with lead blocks of different thicknesses will give the number of rays stopped by each block. If counters are placed above and below an expansion chamber which contains a slab of lead, and which is in a strong magnetic field, the energy lost per centimeter of path by particles traversing the lead can be determined. Street, Woodward and Stevenson have found the following results:

For particles of energy range (Mev)	0–680	680–1150	1150–1900	1900–2500
Average loss (per cm)	45	31	25	20

Not only do these results show that high energy electrons can be as penetrating as photons and that the energy loss per centimeter of path decreases as the energy of the particle increases, but the quantitative results are in good accord with theoretical predictions of the quantum theory. Some cosmic rays are more than 100 times as penetrating as the hardest γ-radiation from natural radioactive substances.

Production of Showers and Bursts

When counters are arranged as in Fig. 2(B), and so connected that only multifold coincidences are recorded, these coincidences increase in number when thin sheets of material are placed above them. This increase is due to cosmic-ray *showers*, which we may define as the radiation emerging from a nonradioactive block of matter when this block is exposed to cosmic rays. A shower contains two or more particles and is detected by three or more G-M counters arranged out of line and so connected that they record only multifold coincidences.

The frequency of showers as a function of thickness of material above the counters is shown in Fig. 13. It is noted that for showers of three or more particles, about 2 cm of lead is

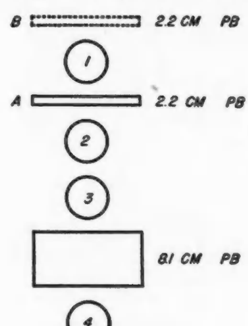


FIG. 12. G-M telescope arrangement to detect penetrating ionizing particles produced by the interaction between non-ionizing radiation and lead.

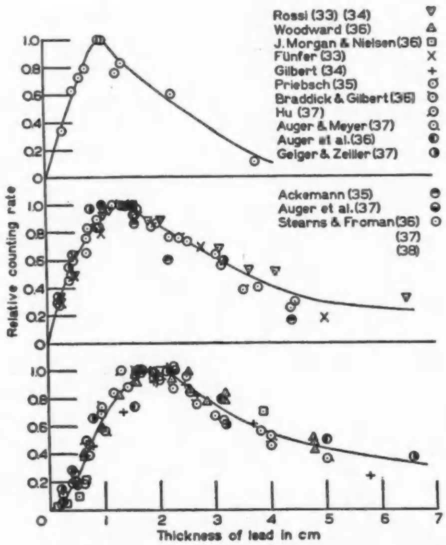


FIG. 13. Variation of the frequency of showers produced in lead with the number of particles in the shower and the thickness of the lead scattering block. The figures in parenthesis indicate the year the data were obtained.

the optimum thickness; for two or more particles, it is about 1.5 cm; and for single secondaries, 1 cm. There is also evidence of another maximum at about 20 cm of lead, not shown in Fig. 13.

The frequency of shower production is also a function of altitude and increases above sea level faster with altitude than does the cosmic-ray intensity as observed by the ionization chamber or cosmic-ray telescope. Morgan and Nielsen, and Froman and Stearns have found that for thin scatterer blocks the number of showers per second varies as Z^2. This is only a very approximate relationship, however, and actually is reversed in the case of zinc and copper.

What is the mechanism by which showers are produced? The most fruitful theoretical work produced in cosmic-ray work so far is that of cascade showers developed independently by Bhabha and Heitler, and Carlson and Oppenheimer. This theory is based on the cumulative pair production by photons and radiation by electrons as set forth in the hypothesis of Bethe and Heitler. Here, three elementary processes are considered: pair production by photons, radiation by an electron, and ionization losses. In the first process a high energy photon, under the influence of the strong electric field due to the nucleus of an atom, disappears and a high energy positron-negatron pair appears. In the second process an electron goes near the nucleus, is accelerated, radiates about half its energy, and proceeds on its journey. In each process we get two rays for one: a photon and an electron; an electron pair ($-e$ and $+e$). These processes continue until the energy of the individual rays becomes so low that the probability of radiation or pair-production vanishes. In developing the theory for such processes, Carlson and Oppenheimer used analytic expressions for the probability of pair production that closely approximate those deduced on the basis of the quantum theory. One of the predictions of this theory is that when a shower passes from material *1* to material *2*, the shower increases in size if $Z_2 > Z_1$ and decreases if $Z_2 < Z_1$. However, the size of the shower is a function only of the second material after it has passed through a predicted thickness of the second element. Morgan and Nielsen have tested this point and the results (Fig. 14) are in qualitative agreement with this prediction. Another prediction of the theory is that the optimum thickness for shower production increases with the number of particles in the shower. This has been tested and the experiments are in good qualitative agreement with the theory. However, the best evidence in support

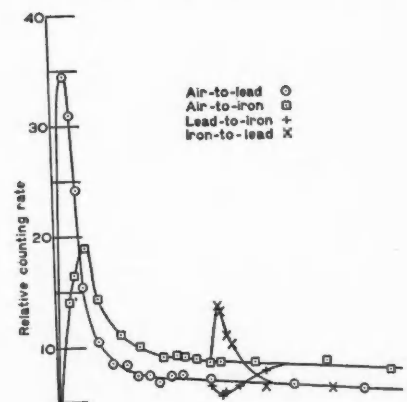
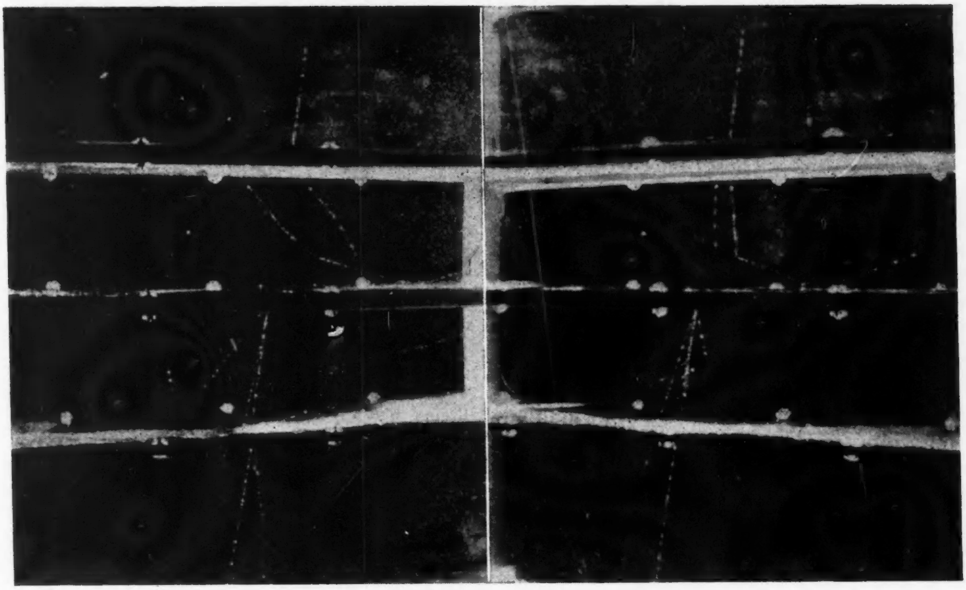
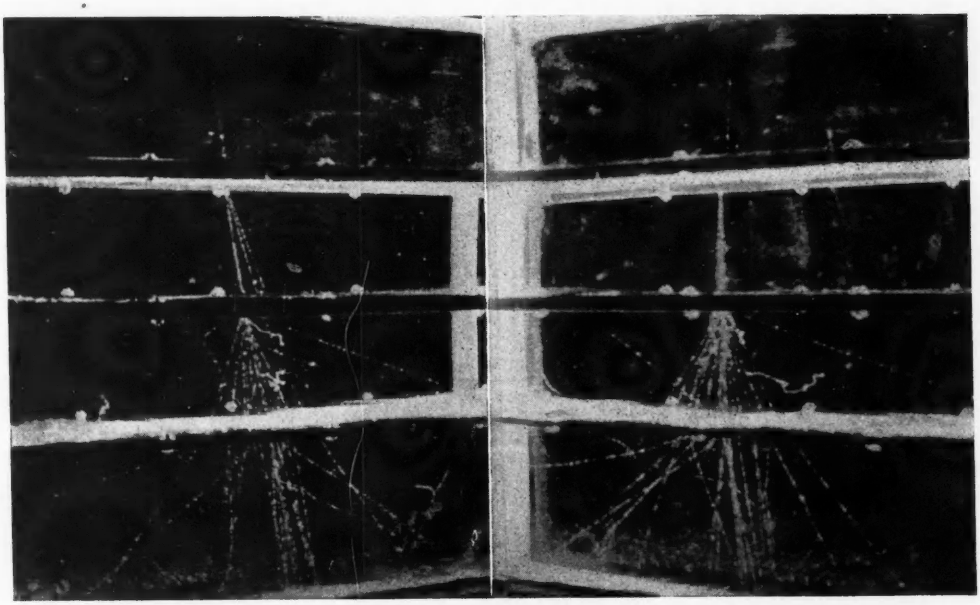


FIG. 14. Data taken with G-M counters which show how the number of showers detected varies with different metals and combinations of metals used as scattering blocks.



(a)



(b)

FIG. 15. Showing the growth of showers by means of divided scattering sheets of lead. In (a) the energy is transmitted from the top to the second plate by means of a non-ionizing ray. [Photographs by courtesy of Messrs. Fussell and Street.]

of this theory is the clear-cut pictures one gets from expansion chambers. Examples are shown in Fig. 15. Thin scattering blocks separated by short distances are placed in the cloud chambers. In Fig. 15(*a*), there is a case where energy is transmitted from the first to the second block by a non-ionizing ray. These photographs give direct and conclusive evidence that showers are produced by the cumulative processes of pair production and radiation.

While the most common type of shower is probably formed in this manner, there seem to be two distinct types of showers. The common type consists of electrons and photons; its particles are well collimated and have transverse momentums corresponding to only a few million electron volts. The number of rays increases on passing through matter until their energy becomes so low that absorption exceeds production and then these showers begin to "tail off." When large, they exhibit no well-defined focus.

In the rarer type of shower, there is a well-defined focus, the particles are not collimated, and heavy recoil particles are seen. Usually the number of particles is small. Such a shower is shown in Fig. 16. To illustrate how fast theoretical work is progressing, let us confess that in the first draft of this article we wrote, "there is no satisfactory explanation of these showers." Since then, Heisenberg and Euler have given a very promising explanation of this type of shower, based on the hypothesis of the spontaneous disintegration of barytrons. According to this hypothesis, the half-life of such particles increases with energy but in no case exceeds a small fraction of a second. When the barytron disintegrates, a neutrino and electron are formed and this may result in the explosion of the nucleus. If barytrons are due to the interaction of non-ionizing radiation with the matter and their half-life is short, this would explain the absence of penetrating charged particles near the top of the atmosphere. This hypothesis also explains why so few barytrons are observed near the end of their range; for the half-life decreases with energy, and the chance of observing one with the low energy it would have near the end of its range is very small. A given layer of air is slightly more effective as an absorber than the same mass of water and air. This is explained on the disintegration of the barytron hypothesis since it takes longer for a barytron to traverse a given mass of air than it does to traverse the same mass of water; hence, more barytrons disintegrate in passing through air, and the products of this disintegration are more easily absorbed than the barytrons. Thus, we might expect the hard component of cosmic rays to be absorbed more readily by an extended absorber than by a compact one of the same mass. This explains why a layer of air equivalent to a meter of water absorbs better near the top of the atmosphere than it does at a greater depth in the atmosphere; and predicts an increase in hardness of cosmic rays with an increase of depth in the atmosphere. The hypothesis produces a better fit between theory and the experimental curves in Fig. 11 than does any previous theory.

Finally, the explosion of the nucleus, predicted by the theory, would produce showers of few particles which seem to move in all directions from one point. Any theory that explains so many existing phenomena is bound to point the way to further experimentation.

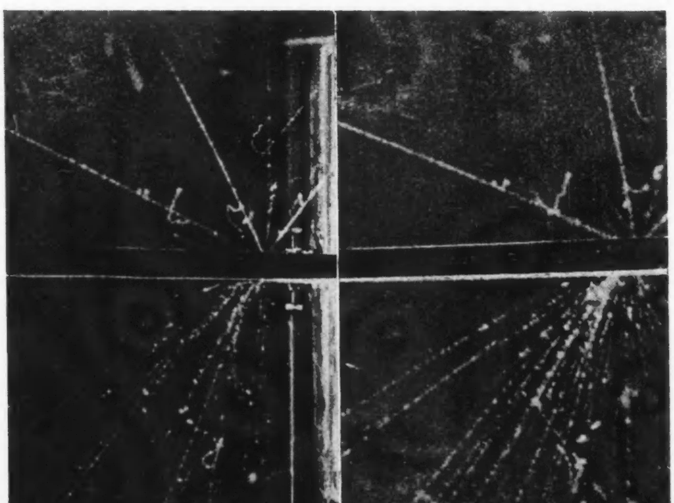


FIG. 16. The rare type of shower where the particles are not well collimated and the tracks are denser than those due to electrons. [Courtesy, Messrs. Fussell and Street.]

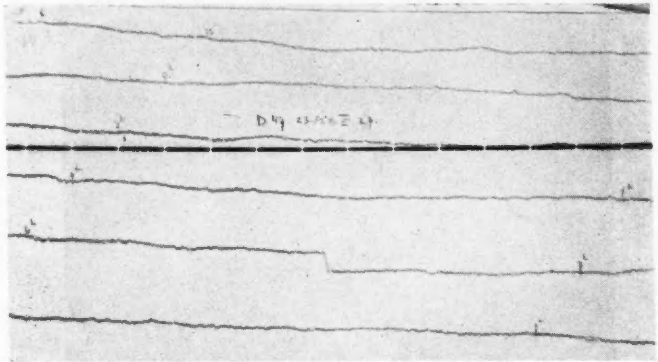


FIG. 17. On June 2, 1927 Hoffman obtained this first photographic record of a cosmic-ray burst. The sharp deflection in the next to the bottom line was caused by the sudden creation of 4×10^6 ions within the ionization chamber. [Courtesy of Professor Hoffman.]

Sometimes showers are so large that they will cause an abrupt change in the current in an ionization chamber. Such phenomena are known as *bursts* or Hoffman Stösse. Fig. 17 shows a picture of the original tracing of this remarkable discovery. Examples of showers large enough to produce such effects are shown in Fig. 18. The number of ions produced by a single burst is of the order of 10^6. Whether or not the common type of shower and bursts is produced by the same mechanism remains to be seen. However, bursts do increase with altitude and there is an optimum thickness of metal for their production; and under favorable conditions, there can be a sufficient number of electrons produced by the pair-production, radiation process to give rise to a burst.

The Positron

One of the most interesting discoveries in cosmic rays is that of the positron, made by Carl Anderson in 1932. The original photograph is shown in Fig. 5(*b*). Three assumptions are possible:

1. The path is that of a positive particle moving downward which loses energy in passing through the 6 mm of lead.
2. Two particles of opposite charge are released from the lead.
3. The path is that of a negative particle moving upward which gains energy by passing through 6 mm of lead.

The corresponding energies of the particle above and below the lead plate are 63×10^6 and 22×10^6 ev. We know of no process whereby a negatively charged particle would triple its energy in passing through 6 mm of lead; thus the comparatively frequent occurrence of phenomena like that in Fig. 5(*b*) rules out assumption 3. By the same reasoning, we may rule out assumption 2; the sharpness of the tracks shows that the two events would have occurred within 0.02 sec of each other, and pictures of this type, with the same density on either side of the absorber, occur so often that assumption 2 is not even a possibility. If it is a positively charged particle, could it not be a proton? If it were a proton, the respective energies on opposite sides of the absorber would be 2×10^6 and 3×10^5 ev, and the specific ionization of a proton for the latter energy is much greater than that of an electron. Also the range of a proton of 3×10^5 ev is only about 0.5 cm in air, while the track in the chamber is 5 cm and shows no loss of energy over the whole track on either side of the lead. If the charge is unity, the loss of energy in the lead plate requires a particle with mass less than the mass of a proton. The specific ionization is definitely that of a particle less than $2e$; hence, we have a particle of mass $<$proton and charge $<2e$. It is interesting to note that the Joliots obtained plates in which electrons seemed to be going in the wrong direction, but had no lead strip in the chamber and thereby missed a discovery worthy of the Nobel prize. At present, one finds a copious supply of positrons in cosmic-ray showers. They are very short lived, however, which perhaps accounts for the lateness of their discovery.

The Barytron (Heavy Electron; Mesotron)

As was pointed out earlier, there is an extremely penetrating component of cosmic rays. Nielsen and Morgan have found that the soft

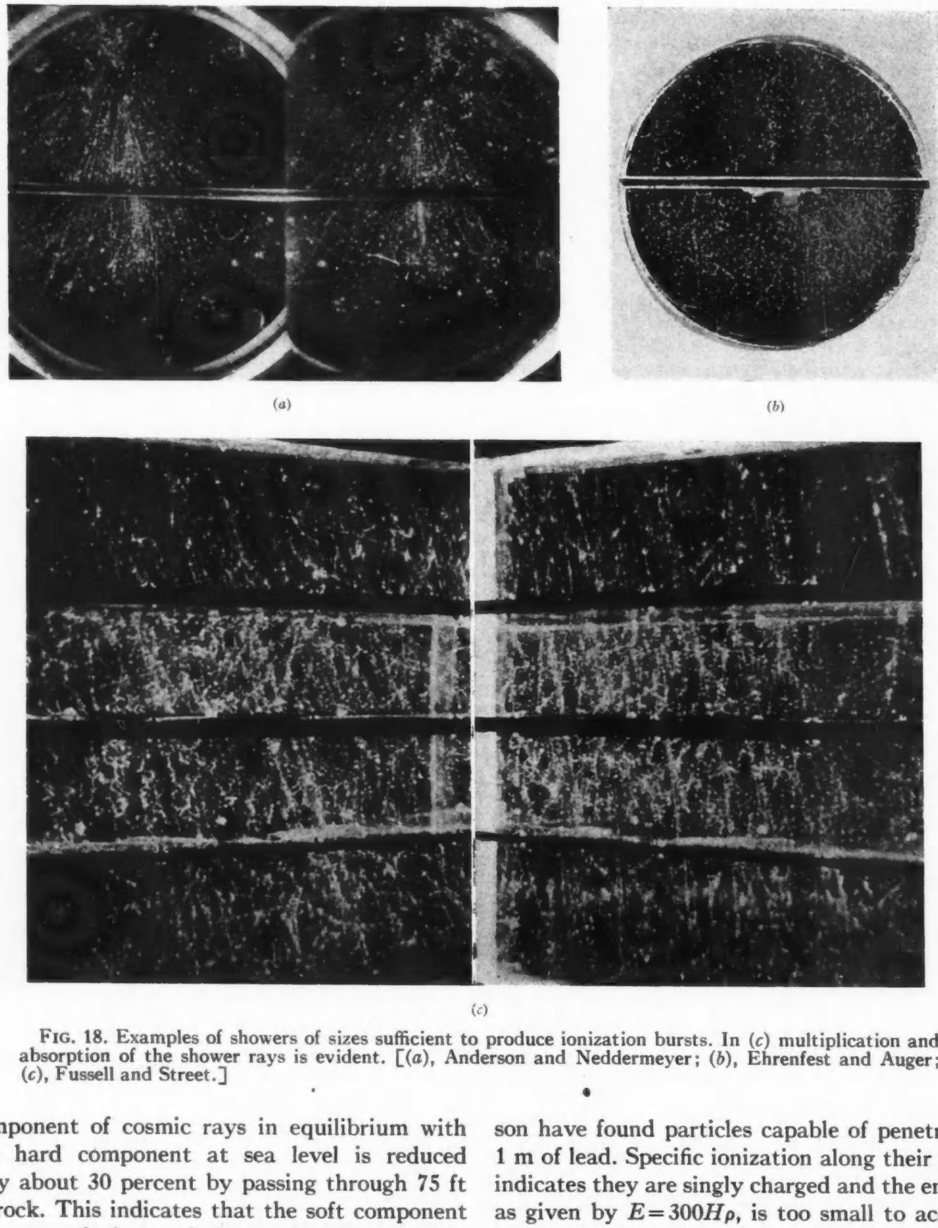


FIG. 18. Examples of showers of sizes sufficient to produce ionization bursts. In (*c*) multiplication and absorption of the shower rays is evident. [(*a*), Anderson and Neddermeyer; (*b*), Ehrenfest and Auger; (*c*), Fussell and Street.]

component of cosmic rays in equilibrium with the hard component at sea level is reduced only about 30 percent by passing through 75 ft of rock. This indicates that the soft component is composed of secondaries produced by another component capable of penetrating 75 ft of rock. The quantum theory, which has been found to be valid for cosmic-ray electrons, indicates that electrons of energy of 10^{10} ev should be absorbed in less than 20 cm of lead, yet Street and Stevenson have found particles capable of penetrating 1 m of lead. Specific ionization along their paths indicates they are singly charged and the energy, as given by $E=300H\rho$, is too small to account for their penetration. Hence, the mass of this particle must exceed that of the electron M_e. In 1936, Anderson and Neddermeyer obtained a disintegration by a non-ionizing ray. The specific ionization of one of the products is higher than that due to an electron. How did they know it

was not a proton? Its range in the argon chamber, if it were a proton, gives it an energy of 1.5 Mev, while the energy as computed by the curvature of the path is 0.16 Mev. It is to be noted that this particle is produced in the lead plate. This is shown in Fig. 5(*e*), while another observation by Anderson and Neddermeyer is shown in Fig. 5(*d*). In the latter, another particle which ionizes more copiously than do the electrons can be seen. The curvature of the track corresponds to a 10^6-ev proton, but such a proton would have a path of only 2 cm while this track is more than 5 cm in length. In the upper part of the chamber, where the energy is higher, this particle does have a specific ionization not much in excess of an electron. The e/m value for this particle is intermediate between that for an electron and a proton. Street and Stevenson have also observed such events, and in one of these events a particle produced a shower when traversing a lead plate. In the apparatus used by them, shown in Fig. 19, G-M counters *1*, *2*, *3*, and bank *4*, are so arranged that the chamber will not be expanded unless an ionizing particle traverses *1*, *2*, *3*, but not *4*; L is a lead block about 10 cm in thickness and is used to absorb most of the cosmic electrons; C is a Wilson cloud chamber which can be expanded 1 sec after a particle has traversed *1*, *2*, *3*, but not *4*. Thus, the conditions are good for photographing the track of a penetrating particle near the end of its path, and the ions have diffused enough to permit a comparison of the specific ionization of different tracks. Of 1000 tracks, 2 were found where ionization along the track was heavier than for the others. These are shown in Fig. 20. The value for $H\rho$ is 9.6×10^4 for the track shown in Fig. 20(*a*). The range is >6.0 cm of air, while that of a proton with this value of $H\rho$ would be 0.9 cm. The estimated mass is 130 ± 25 percent M_e. In Fig. 20(*b*) the track shown has a specific ionization of 4 times that of an electron and has an $H\rho$-value of $1.8\times 10^4\pm 10$ percent. This leads to an estimated mass of $1900M_e$ and this track is evidently due to a proton.

Direct measurements of energy loss, atmospheric absorption, and shower production with thin scatterers show that the Bethe-Heitler theory holds for electrons of energies as great as 10^{10} ev. And if this theory holds, the latitude effect should extend only to 35°, whereas experiments show it extends to 50°. Furthermore, one cannot account for the great penetrating power of some of the cosmic rays on the basis that they contain only electrons and photons. Not only do direct experiments with expansion chambers indicate a very few positive protons and no negative ones, but there is direct evidence of

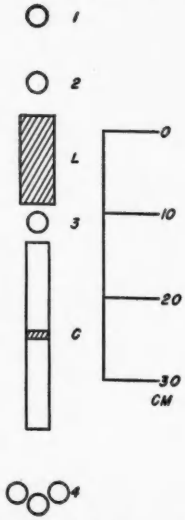


FIG. 19. Combination of G-M counters and expansion chamber used to determine the nature of penetrating cosmic-ray ionizing particles. The cloud chamber C contains a strip of lead.

particles, both positive and negative, of mass intermediate between the mass of the electron and that of the proton. A number of workers have performed experiments that enable them to estimate the mass and such estimates vary between 100 and $500M_e$. What is this new particle, the barytron?[4] Is it secondary in nature? Are the divergent values due to the difficulty of experimentation, or is it possible that these barytrons are electrons in excited mass states? This is a most fertile field which is being investigated by many capable workers and we may expect an answer to these questions. The discovery of the barytron, however, has made it unnecessary to assume any longer the presence of protons and α-particles to account for the penetrating component of the cosmic rays.

[4] Anderson and Neddermeyer prefer the name *mesotron*, which designates an intermediate particle, rather than *barytron*, which suggests a heavy particle.

(a) (b)

FIG. 20. (a), track of a barytron; (b), track of a proton. The difference in density of the tracks is easily discernible.

Neutrons and Neutrettos

Heitler has worked out the nuclear cross sections for the reactions,

$$h\nu+P=Y^{+}+N, \quad (11)$$

$$h\nu+N=Y^{-}+P, \quad (12)$$

which seem sufficiently probable to account for the whole penetrating component. Heavy-particle showers may be originated by some process similar to

$$Y^{+}+N=P+Y^{+}+Y^{-}. \quad (13)$$

In these equations, Y denotes a barytron, P a proton, N a neutron; and h and ν have their usual significance. The P and N on the left side of Eqs. (11) and (12) may be in the atomic nuclei. Reactions of the type represented by either of these equations would account for the production of penetrating, ionizing rays observed by Schein and Wilson. These equations indicate that there is a neutron component in cosmic rays.

Froman and Stearns have performed experiments to test for this neutron component. The experiments are based on the fact that neutrons interact with substances rich in hydrogen to produce protons. Paraffin is an excellent substance for this purpose; hence, neutral cosmic-ray particles on passing through paraffin should produce charged particles. Since neutral particles do not set off G-M counters and charged particles do, the arrangement shown in Fig. 21 was used. The counters are arranged in the form of a triangle. The bottom two are surrounded by 10 cm of lead; very few electrons can penetrate this amount of lead. A block of lead 2 cm in depth is placed above the top counter, while a block of paraffin alternately occupies positions *A* and *B*, respectively. The paraffin is equally effective as an absorber in either position. With paraffin in position *A*, ionizing particles, produced in the paraffin by neutrons and passing through counters *1*, *2*, and *3* simultaneously, will be recorded; while, when it is in position *B*, such ionizing particles will, in general, pass only through counters *2* and *3*. Hence the difference in count with the paraffin in the two positions is a test of whether there is a neutral component in cosmic rays. The frequency of counts is 10 percent higher when the paraffin is in position *A* and this is definite evidence that there are neutrons or neutrettos in cosmic rays. Another experiment indicates that the penetrating cosmic rays are readily absorbed by paraffin. The *neutretto* is a neutral barytron, and Shonka and others have obtained some evidence for its existence.

Biological Effects

Have the physicists been playing with high energy particles that have a significant value in other fields? Muller reported a decrease in the rate of mutations of drosophila when they were confined in deep caverns where the cosmic-ray intensity is low. Jollos placed drosophila on Pike's Peak, and found a significant increase in the mutation rate during two months but none the following month. As the flies were under a metal stairway during the first two months but not during the third month, could it be that the effect was produced by cosmic-ray showers produced in the metal stairs? The next summer fruit flies were placed in the Mt. Evans laboratory, some under metal so as to be radiated with shower particles from the metal, some with no metal above to be radiated with the atmospheric cosmic-ray particles. Another group was left at sea level for control. The right to publish the findings belongs, of course, to Professor Jollos; but we think he did a good piece of detective

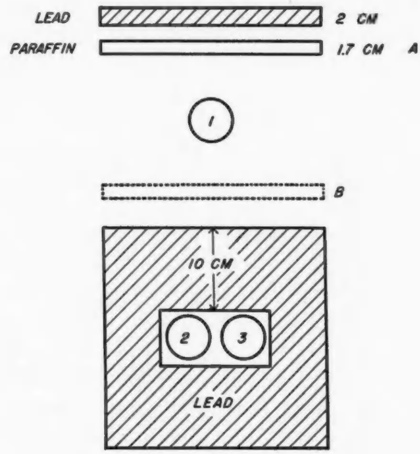


FIG. 21. Apparatus used to test for neutrons in cosmic rays.

work in suspecting the steel staircase, and the reader's guess is probably correct. Workers in physics will be interested to read of the results where the drosophila were exposed for a longer period than had been planned.

The results in the field of physics alone justify all the effort and money which have been expended in cosmic-ray investigations since 1903, for these rays furnish us particles of higher energy than is now available artificially in any laboratory. Such particles are used to test theories which predict the behavior of an electrical particle moving in an intense electrical field due to a nuclear charge. To be specific, it is found that the loss in energy of a high energy electron in passing through lead is that predicted by quantum theory. We can now use this theory with assurance because it has been tested in the laboratory; but no such test would have been possible if the cosmic-ray high energy electrons had not been discovered. The production of a positron and an electron by a high energy γ-ray is actually seen in an expansion chamber—

further evidence of the interchange of mass and energy. The discovery of the positron and the barytron are the direct results of cosmic-ray research. It seems we may be on the verge of watching a nucleus explode. In fact, cosmic rays may become as useful to the physicists in examining the nucleus of the atom as x-rays have been in exploring the planetary electrons. Lastly, the very existence of high energy electrons is an incentive to the scientist in the laboratory to build machines that will produce charged particles of equally high energy. It is a long way from the collapsing leaves of an electroscope in 1903 to the picture of an exploding nucleus in 1938, from the 100-kv x-ray machine to the 5000-kv cyclotron. The number of important problems to be solved is ever increasing, but scientific progress is being accelerated and the recent past predicts a most interesting future.

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Physics in American Colleges Before 1750

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A RECENT article[1] states that science instruction in this country began around 1750. It is difficult to state definitely when science actually entered the curriculum, but this date is probably not far wrong.

While the present article will be confined to the teaching of physics or natural philosophy, it should be realized that it, together with astronomy, comprised all the instruction in science commonly given in the colleges during this period. The secondary schools did not have any science courses until the founding of the first academy in 1749.

This period might be divided into two parts: The first began with the opening of Harvard in 1638 and extended to the beginning of the downfall of Aristotelian physics, which was certainly in progress by 1687; the second, a transitional period, during which physics was evolving into a science, ended around 1740.

New Englands First Fruits[2] mentions physics, astronomy, and "The Nature of Plants" as part of the curriculum of Harvard in 1642. It even lists, in Latin, fifteen theses "Physicas" which may have been debated at the first Harvard commencement in 1642. Translating a few of these, we learn that "Form is an accident," "Form is the principle of individuation," "Whatever is moved is moved by another (thing)," and "Putrefaction in a damp place arises from external heat," were then considered within the domain of physics. That the subjects of early Harvard theses were stable medieval disputations has been pointed out by Morison[3] and by Walsh.[4] Harvard in its early years was anxious to impress its English friends by duplicating the curriculum of the English universities, and this was the kind of natural "science" they were then teaching.

While "The Nature of Plants" seems to have disappeared from the curriculum, physics and astronomy remained. However, natural philosophy, as physics was called during the eighteenth and most of the nineteenth centuries,

[1] D. Roller, Am. Phys. Teacher **6**, 244 (1938).
[2] London, 1643.
[3] S. E. Morison, *Harvard College in the Seventeenth Century* (Harvard Univ. Press, 1936), p. 227.
[4] J. J. Walsh, *Education of the Founding Fathers of the Republic* (Fordham Univ. Press, 1935).

included all natural phenomena—both animate and inanimate, terrestrial and celestial.

The character of the physics textbooks of this period was quite unscientific.[5] Peripatetic or scholastic physics, as Aristotelian physics is called, is generally characterized as an attempt to determine the "why" of nature. Textbook writers in those days selected passages from Aristotle to which they added comments from various authorities. Aristotle's views in the realm of physics were little more than opinions based on common observations. Starting with these, both he and his commentators hoped to arrive at some universal truth by means of deduction.

It is impossible in this brief discussion to outline the contents of these Aristotelian textbooks fully. The general idea was to explain the *raison d'etre* of the entire universe from the stars to the center of the earth, with the physiology of animals and plants, and a little psychology thrown in for good measure. Considerable space was used in trying to define "time," "space," "causality," "motion," and the like.

Latin was the language in which the Aristotelian texts were written and the college laws compelled its use in the classroom. No mathematics, problems, experiments or experimental results, and few illustrations, graced these books. The teacher had no need to demonstrate the principles contained in them—in fact, no apparatus was available for such demonstrations—and the student was excused from the solution of physics problems as well as from laboratory work. The methods employed in class were to read the text, and to outline, discuss and dispute the principles contained in it. At graduation some of these principles might be used as theses to be defended or refuted according to the rules of syllogistic argument.

The first physics at Yale was also Aristotelian. "Pierson's Manuscript of Physicks," which seems to have been copied and studied by the students in lieu of a regular textbook, was based on an Aristotelian text and the notebook of Dr. Abraham Pierson.[6] Schwab[7] speaks of the use of the less metaphysical works, Jean Leclerc's *Physica* and Jacques Rohault's *System of Natural Philosophy*, in the 1720's.

Like Harvard and Yale, William and Mary also taught Aristotelian physics. The college laws of 1736 state:[8]

> Forasmuch as we see now dayly a further progress in Philosophy, than could be made by Aristotle's Logick and Physicks, which reigned so long alone in the schools, and shut out all other; therefore we leave it to the President and Masters, by the advice of the Chancellor, to teach what Systems of Logick, Physicks, Ethicks, and Mathematicks, they think fit in their schools.

Princeton seems to have taught scientific physics from its opening in 1747. This is concluded from the fact that a Princeton student of 1750 wanted a copy of Benjamin Martin's *Philosophia Britannica*,[9] a truly scientific work. Also a college publication of 1752 mentions the need of ". . . a proper Apparatus for Philosophical Experiments; . . ."[10] The University of Pennsylvania and all other colleges established thereafter taught scientific physics from the beginning.

When did the period of Aristotelian science end? Morison[11] places the change in astronomy at Harvard as beginning before 1659, with the introduction of the works of Copernicus, Galileo and Kepler, and the consequent banishment of the Ptolemaic system. With regard to physics he has concluded[12] that Charles Morton's semi-scientific *Compendium Physicae* was in use there before 1687. As was pointed out previously, Yale departed from Aristotelian physics in the 1720's, William and Mary in 1736.

The foregoing dates do not mean that Aristotelian science was entirely forgotten. The attempt was made to teach both Aristotle's physics and the new physics formulated by Newton and the rest—somewhat like the attempt in our day to teach both the classical

[5] See S. E. Morison (reference 3, pp. 225–26) for a discussion of the textbooks that were probably used at Harvard in this period.

[6] L. F. Snow, *The College Curriculum in the United States* (New York: By the Author, 1907), pp. 32–33.

[7] J. C. Schwab, "The Yale College Curriculum 1701–1901," Educational Review 22, 5 (June, 1901).

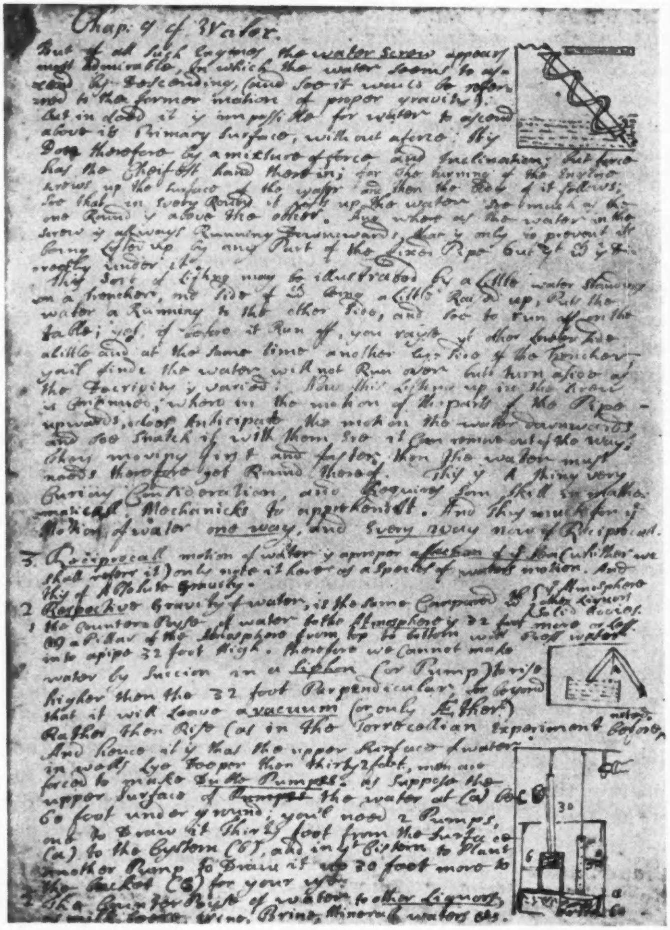
[8] Statutes of the College of William and Mary in Virginia 1736, *Bulletin of the College of William and Mary*, Vol. VII, No. 3 (Jan., 1914), p. 14.

[9] John MacLean, *History of the College of New Jersey from its Origin in 1746 to the Commencement of 1854* (J. B. Lippincott and Co., 1877), Vol. 1, pp. 141–42.

[10] *A General Account of the Rise and State of the College Lately Established in the Province of New Jersey* (Princeton, 1752), p. 7.

[11] Reference 3, p. 216.

[12] Reference 3, pp. 238–49. The *Compendium Physicae* was not printed but was copied by the students.


Chap: 4 of Water.

An extract from Morton's *Compendium Physicae*, copied by Nathaniel Eells of the Harvard class of 1699. [Yale University Library.]

and modern theories of radiation. For this reason it seems appropriate to call this a transitional period, since in it physics was evolving into a science.

Some portions of the textbooks[13] used during this transitional period were scientific in that they were based on experiments, observations and mathematics, whereas other portions were Aristotelian. The following quotation[14], from Rohault's preface to his book, previously mentioned, might help to show the general feeling toward Aristotle in this period:

> Further you will not find a great many Things in this whole Treatise contrary to Aristotle; but you will find more than I could wish that are contrary to most of the Commentators upon him: And besides you will meet a great many Things, which neither Aristotle nor his Followers have treated of at all, which I have however judged more useful than many others which Philosophers have wholly imployed themselves in. And in all this I did not think it very ill in me to depart from some particular Notions, when I found that these Notions were disagreeable to Truth.

Rohault follows the practise of the Aristotelian commentators in giving space to the opinions of various authorities. Thus he has chapters headed: "Of the Elements according to the Opinions of the Ancients," "Of the Elements of the Chymists" and "Of the Elements of Natural Things." Considerable attention is devoted to the definitions of form, essence, alteration, corruption, etc., as in the Aristotelian books. Like them also is the teleological note which is present in many parts of the book.

On the other hand, the section on geometrical optics differs but little from that found in recent textbooks. It has many diagrams, illustrating the principles of mirrors and lenses, which plainly suggest to the reader that he may check up on these principles himself. The astronomical section is also scientific. Some of the principles are demonstrated mathematically, usually in the footnotes.

Another thing, which plainly indicated that physics was becoming a science in the early half of the eighteenth century, was the increasing mention of "philosophical apparatus." An account[15] of the burning of William and Mary

[13] Reference 3, pp. 232–34. On these pages are listed the transitional books probably used at Harvard.

[14] Translated by John Clarke (London, 1723). Some material was added by him.

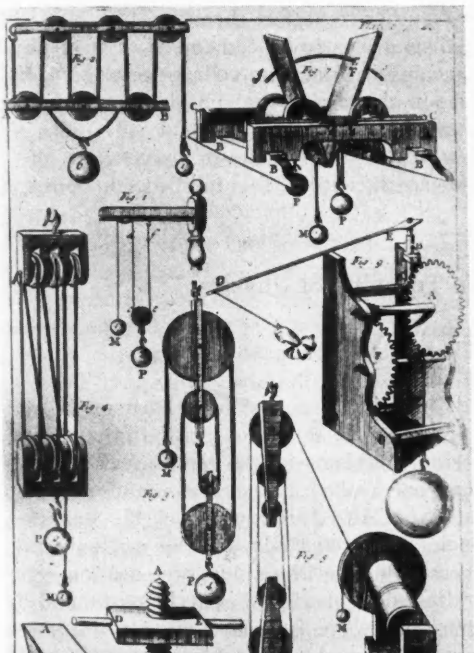
[15] *The History of the College of William and Mary from its Foundation 1693 to 1870* (John Murphy and Co., 1870), p. 35.

College, in 1705, mentions the destruction of the philosophical apparatus; Harvard[16] received some apparatus from a benefactor in 1727; Yale[17] was promised some in addition to what it had already in 1719. While philosophical apparatus included such things as globes, telescopes, and surveying instruments, the apparatus previously mentioned in connection with Harvard and Yale was intended for experiments in physics.

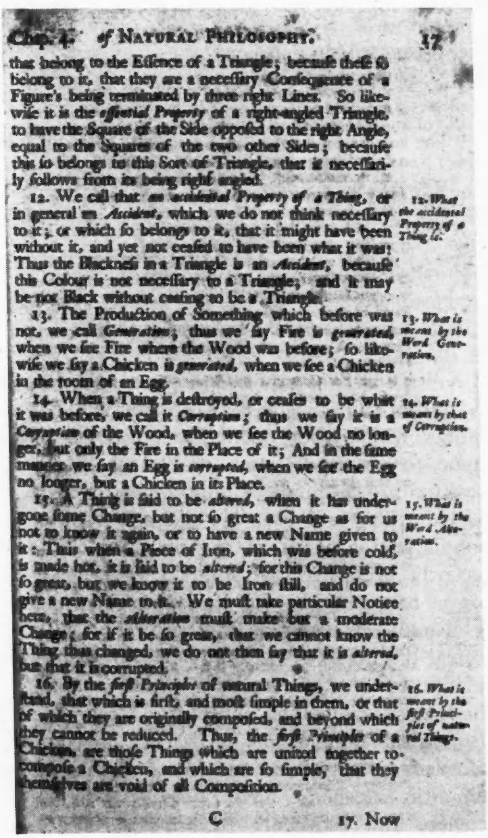
The use of apparatus produced one important innovation in the teaching of physics, namely, the demonstration. It arose from the belief that when a student saw a principle demonstrated by means of apparatus, he would better understand it. Eventually this led to the establishment of laboratory work in the nineteenth century.

With the advent of textbooks written in English, the necessity of reading the text in class vanished. Students were now expected to memorize the assignment and be prepared for a barrage of questions from the teacher. As physics became more and more scientific, the importance of the disputation, with its emphasis on the opinions of authorities and on deduction, declined.

Another sign of the times was the extension of science teaching to the secondary schools through the academy movement. The first academy is generally conceded to have been the one founded in Philadelphia in 1749 with Benjamin Franklin as one of its promoters. It evolved into the University of Pennsylvania. Franklin's advocacy of scientific education is so well known that it is unnecessary to dwell on it here.



A plate from van s'Gravesande's *Mathematical Elements of Natural Philosophy* (1726). [Columbia University Library.]



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that belong to the Eſſence of a Triangle; becauſe theſe ſo belong to it, that they are a neceſſary Conſequence of a Figure's being terminated by three right Lines. So likewiſe it is the *eſſential Property* of a right-angled Triangle, to have the Square of the Side oppoſed to the right Angle, equal to the Squares of the two other Sides; becauſe this ſo belongs to this Sort of Triangle, that it neceſſarily follows from its being right angled.

12. We call that *an accidental Property of a Thing*, or in general an *Accident*, which we do not think neceſſary to it; or which ſo belongs to it, that it might have been without it, and yet not ceaſed to have been what it was: Thus the Blackneſs in a Triangle is an *Accident*, becauſe this Colour is not neceſſary to a Triangle; and it may be not Black without ceaſing to be a Triangle. *12. What the accidental Property of a Thing is.*

13. The Production of Something which before was not, we call *Generation*; thus we ſay Fire is *generated*, when we ſee Fire where the Wood was before; ſo likewiſe we ſay a Chicken is *generated*, when we ſee a Chicken in the room of an Egg. *13. What is meant by the Word Generation.*

14. When a Thing is deſtroyed, or ceaſes to be what it was before, we call it *Corruption*; thus we ſay it is a *Corruption* of the Wood, when we ſee the Wood no longer, but only the Fire in the Place of it; And in the ſame manner we ſay an Egg is *corrupted*, when we ſee the Egg no longer, but a Chicken in its Place. *14. What is meant by that of Corruption.*

15. A Thing is ſaid to be *altered*, when it has undergone ſome Change, but not ſo great a Change as for us not to know it again, or to have a new Name given to it: Thus when a Piece of Iron, which was before cold, is made hot, it is ſaid to be *altered*; for this Change is not ſo great, but we know it to be Iron ſtill, and do not give a new Name to it. We muſt take particular Notice here, that the *Alteration* muſt make but a moderate Change; for if it be ſo great, that we cannot know the Thing thus changed, we do not then ſay that it is *altered*, but that it is corrupted. *15. What is meant by the Word Alteration.*

16. By the *firſt Principles* of natural Things, we underſtand, that which is firſt, and moſt ſimple in them, or that of which they are originally compoſed, and beyond which they cannot be reduced. Thus, the *firſt Principles* of a Chicken, are thoſe Things which are united together to compoſe a Chicken, and which are ſo ſimple, that they themſelves are void of all Compoſition. *16. What is meant by the firſt Principles of natural Things.*

C 17. Now

A page from Rohault's *System of Natural Philosophy* (1723). [Columbia University Library.]

[16] Benjamin Peirce, *A History of Harvard University* (Brown, Shattuck and Co., 1833), p. 151.

[17] F. B. Dexter, *Documentary History of Yale University* (Yale Univ. Press, 1916), p. 193.

The transitional period ended at Harvard and Yale before 1740. Harvard[18] was probably using van s'Gravesande's *Mathematical Elements of Natural Philosophy*, a scientific work, before 1737. Yale students appear to have used the 1731 edition of this work.[19] William and Mary[20] was teaching scientific physics by 1758, but whether it went through a transitional period between 1736 and 1758, the writer is not able to say definitely.

An examination of several editions[21] of the van s'Gravesande book plainly indicates that it relies upon experiments to prove the truth of its principles, rather than the opinions of authorities. Despite its title, it consists almost entirely of descriptions of experiments and uses mathematics sparingly. This textbook was one of the first to confine itself to the field of inanimate nature. In order to explain the experiments properly, it made use of many more illustrations than did the books of the transitional period. Like the other early scientific textbooks in physics, it gave much attention to astronomy, optics and mechanics. Sound, electricity and heat received a few pages each, while magnetism is barely mentioned.

The reason for the stress on astronomy, optics and mechanics lay in the fact that they were well developed and could readily be explained by observation and experiment. Sound does not constitute a very big part of a general physics book even today. While there was some factual information available on heat, electricity and magnetism, theoretical knowledge in those fields was in a very low state. This may have caused the author to neglect them.

This brings to an end the account of physics teaching in American colleges prior to 1750. It was in this period that physics changed from a metaphysical subject, not at all unlike that taught in the medieval universities of the thirteenth century, to a full-fledged science.

[18] Reference 16, p. 237.
[19] Reference 7, p. 5.
[20] G. W. Ewing, "Early Teaching of Science at the College of William and Mary," Bulletin of the College of William and Mary, **32**, 4, Apr. (1938), p. 5.
[21] The editions published in London in 1726, 1737 and 1747; translated from the Latin by J. T. Desaguliers.

General Semantics and the Teaching of Physics

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IN RECENT years the problem of meaning and of the relation between symbols and the things which they symbolize (referents) has come to occupy a more and more important position in the minds of philosophers, scientists, psychiatrists, and even lay people. Witness the popularized account of the work in this field recently presented by Stuart Chase,[1] and one begins to realize the widespread interest in what is usually considered an essentially difficult logical discipline. That many of the issues considered by the semanticists (from *semantics*—the science of meaning) are of prime relevance in the logical foundations of science is common knowledge; but that certain of the practical semantic methods have *pedagogic* value in science, and especially in physics, is not so generally appreciated.

The particular system of semantics which appears to me to be most useful in coping with certain problems in the teaching of physics is that one (called "General Semantics") formulated by Alfred Korzybski in his remarkable book, *Science and Sanity*.[2] This original work is necessarily repetitious in its presentation—it was addressed primarily to psychiatrists and laymen—but there is such a wealth of pertinent material throughout the volume that the patient reader will be amazed at the wide applicability of the methods outlined in it.

Before pointing out the specific applications to physics teaching, I shall give a very brief summary of the major ideas of general semantics. Probably the key phrase of the whole system is "similarity of structure." Korzybski uses this

[1] S. Chase, *The Tyranny of Words* (Harcourt-Brace, 1938).

[2] A. Korzybski, *Science and Sanity* (Science Press, 1933).

phrase in the same sense as Russell:[3] A relation P between members of an ensemble x_p has the same structure as a relation Q between members of an ensemble x_q, if there is a one-to-one correspondence between the elements of x_p and x_q such that whenever two elements of x_p are in the P relation to each other, their correlates in x_q are in the Q relation to each other, and vice versa. To illustrate this definition, an accurate map of the United States has the same structure as the actual territory, since on both map and territory Chicago is between New York and San Francisco. In this example the relation P would be the spatial order of the three cities, which are the elements x_p; Q would be the spatial order of the points on the map representing these cities, and these points would be the elements x_q.

Having defined "similarity of structure," Korzybski proceeds to his three fundamental premises which restrict the relation between the external reality (the territory in the previous example) and the symbol (map) for the territory: (1) *The map is* **not** *the territory.* (2) *The map does not represent* **all** *the territory.* (3) *The map is self-reflexive.*

The simplicity of the first statement is disconcerting. Every "sane" person knows that the words, symbols, equations, etc., by means of which we refer to the external world are not the external world, which is nonlinguistic and impersonal. But the implication of this assertion is far-reaching. Since symbols are not the things symbolized, the only connection between symbols and the things symbolized must be structural; in other words, the essential content of knowledge is structural.[4] The symbols by which we know an external reality must resemble that reality in structure. Thus the symbol "dog" for a four-legged animal that barks is, when taken by itself in complete isolation from any aspects of the object dog, quite useless (except as a proper name), since there are no structural implications between the noise "dog" and its referent; but the sentence "dog barks" is a relation between the two words, "dog" and "barks," that is structurally similar to the actual behavior of the dog, and hence it has content. We have no knowledge of the object "dog" by knowing the noise "dog," but we do have some knowledge of the dog when we know the sentence "dog barks," which is structurally similar to the objective dog barking. Again, in physics, we always deal not with objects in complete isolation but with the connections or structural relations between objects. Symbols like g, f, m, a, etc., represent structural entities arrived at by observing certain relations between clocks, dial readings, and the like. Moreover, the symbol g is useless (except as a proper name), unless it is contained in some sentence like $s=\frac{1}{2}gt^2$, which is structurally similar to the external reality.

The second fundamental premise is, of course, perfectly obvious—no two things are identical in *all* respects. Thus we can never hope to have a perfect symbol, for a perfect symbol would have an infinite number of aspects corresponding to the actual infinity of physical attributes of any real event. We arrive at our symbolic formulations by a process of abstracting the relevant from the irrelevant: In setting up the equations of motion of a planet in the sun's gravitational field, we use the fact that the sun has such and such mass, but we do not use the fact that the planet has a low albedo or that its chemical composition is chiefly iron. This tendency of our symbols to represent only part of the truth is called "elementalistic" by Korzybski. In order to overcome the misleading effects of the elementalism of symbols, and to insure conscious awareness of this elementalism by users of symbols, Korzybski suggests the use of five simple "semantic devices:"

(1) *Quotation marks:* Elementalistic terms that imply a dichotomy which can never exist in nature are to be enclosed in quotation marks: for example, "body," "mind," "motion," "matter," "space," "time;" etc.

(2) *Hyphens:* Elementalistic terms may be combined with a hyphen between them to construct "nonelementalistic," or at least "less-elementalistic," terms: for example, space-time, body-mind, etc.

(3) *Et ceteras:* Since in any case not all characteristics of a referent can ever be included in a symbol, the abbreviation *etc.* is to follow every symbol to indicate that the user of the symbol is aware of the things left out by the symbol.

(4) *Dates:* Since many symbols cannot have validity for all time, the dates of validity are to be given: for example, science, 1938; quantum mechanics, 1938; etc.

[3] B. Russell, *The Analysis of Matter* (Harcourt-Brace, 1927).

[4] Cf. Spinoza, who says in his *Improvement of Understanding:* "Ordo et connexio idearum est accordo et connexio rerum." [The order and connection of ideas is the same as the order and connection of things.]

(5) *Indices:* Since no two objects are precisely and entirely identical in *all* respects, indices are to be appended to symbols to focus attention on the absolute individuality of objects: for example, $chair_1$, $chair_2$, etc.

The semantic devices are childishly simple; yet it is precisely this simplicity that makes them so powerful in overcoming misapprehensions and improper evaluations occasioned by misuse of symbols. The elementalism which the devices are designed to combat is such a fundamental part of our everyday life—elementalistic thinking is so deeply ingrained in our nervous systems—that only devices of extreme simplicity, which can themselves become deeply rooted in our cerebral cortex, can possibly be effective in rooting out the bad effects of our everyday thinking and speaking habits.

The third fundamental premise refers to the fact that we can have symbols of symbols, maps of maps, etc. Our language contains words of varying degrees of abstraction—the lowest abstractions refer directly to things, the higher to other words and symbols. This notion of "order of abstraction" is treated by an ingenious diagram called the "Structural Differential." By means of the Structural Differential, Korzybski shows how the hierarchy of symbols is built up: first, there is the nonlinguistic event in space-time having an infinity of characteristics; next there is the object—for example, an apple—as we see it and therefore not containing all the characteristics of the event; third, there is our description of the apple; fourth, there are a series of inferences of low order about the apple, each one leaving out characteristics from the one before it; and finally, there are inferences of high order. Confusion of orders of abstraction is a semantic blunder which is only too common among all of us, raised, as we are, in an elementalistic world.

There are, of course, many aspects of Korzybski's system that cannot be touched in this brief review; however, the summary given will serve to show what implications the system has in the clarification of certain problems arising in the general pedagogy of science, and, particularly, of physics.

Applications to the Teaching of Physics

The task which confronts the student when he is trying to learn some phase of physics consists, in ideal cases, of three parts: first, he must acquaint himself with the actual series of experiments that comprise the domain of physics to be learned; second, he must acquaint himself with the relevant symbols (including terminology, formulas, etc.), and with some of the standard schemes for manipulating these symbols; and finally, he must be able to bridge the gap between the symbolism of physics and the experimental facts which the symbols represent.

If physics were the only course in the curriculum, this sharp separation could, perhaps, be maintained. Each student would presumably be given sufficient time and equipment to perform all of the fundamental experiments on which the science of physics is based. He would then learn the symbols which refer to these experiments, and there would be no danger of confusing the two. But, of course, this is impossible in practice, and so the first two steps in the learning process are always combined. Symbols, whose experimental referents are well known to the student, are continually being used to define new symbols which, for the time being, may or may not have experimental referents as far as the student is concerned.

A constant appreciation of the natural order of understanding—descriptions before inferences, abstractions of low order (and hence high degree of validity) before abstractions of high order (and possibly less validity)—is absolutely necessary if the student is to gain any insight into physics, and science in general, for that matter.[5] But because the experimental and theoretical approaches are inextricably interwoven in actual physics courses, this natural order too often escapes the student, and he acquires a false sense of security in knowing certain neatly cubby-holed (and therefore readily learned) high abstractions, while entirely overlooking the low order abstractions—experimental facts.

The learning of the symbolism of physics is not a very difficult task if the student has sufficient mathematical background. (Of course, I realize that this mathematical background is often lacking in practice, but that is really a problem

[5] Cf. V. F. Lenzen, *The Nature of Physical Theory* (Wiley, 1931), where he distinguishes between experimental, theoretical, and mathematical physics. For our purposes we need not distinguish between mathematical and theoretical physics; that is, between the symbolism and its manipulatory technics, or syntax.

for the teachers of pure mathematics.) It is in this respect that physics is essentially simpler, at least from the semantic point of view, than other sciences (1938): the syntax of its language (mathematics) has been more carefully worked out than the syntax of the ordinary languages. Hence, manipulation of physics symbols follows certain perfectly defined patterns which, when once learned by the student, are universal. This cannot be said of the symbolism of the social sciences, which is primarily verbal.

The third phase of the learning process —finding correlations between symbols and referents—presents the greatest difficulty, and it seems to me that it is just here that the semantic discipline is most helpful. As I have already implied, the acquisition of a nonverbal, nonsymbolic contact with physical reality is relatively easy, given sufficient laboratory experience; on the other hand, facility in manipulation of physics symbols is acquired as easily as any other mathematical technic. If the third task, which consists essentially in noting similarity of structure between symbols and physical referents, could be made as easy as the other two, physics would no longer have its reputation for being the most difficult undergraduate course in the curriculum.

It will be recognized that this ability to find similarity of structure between symbols and referents is the essence of "physical intuition." A person has good physical intuition if he can choose from the flock of physics symbols which he commands those symbols whose structure is most like the structure of the physical reality, and if he can recognize structure in the physical reality to which he can make correspond known symbols of similar structure. How can this "nose" for structural similarity between symbols and facts be developed in students? It has been my observation during the past year that simply pointing out the facts and methods outlined in the first part of the paper has given some students an awareness of the problem, which awareness, in itself, has proved helpful. Whether or not other more specific semantic schemes for developing physical intuition will appear in the future, I cannot say at present; however, the history of the application of general semantics in other fields (psychiatry, elementary education) during the last five years would lead me to expect an affirmative answer.

Common Semantic Blunders

I will list several common blunders which are well known to physics instructors but, so far as I am aware, have never been analyzed semantically; it is to be hoped that this semantic analysis will suggest new methods for correcting these blunders.

1. Confusion of inferences with descriptions.—This blunder comes under the general heading of confusion of orders of abstraction; it may be illustrated by the student who can state with extreme accuracy the symbolism of the kinetic-molecular theory but cannot quote the experimental evidence upon which it is based. This tendency is particularly noticeable among students of a highly abstract subject such as quantum mechanics or atomic spectra, where the experimental basis is often lost sight of even by the teacher; it is all the more to be deplored because it lulls the student into a state in which he thinks he knows physics when what he knows is symbols.

2. Substitution of facility in the use of symbols for understanding of structural similarity.—This, the basis of the common complaint, "I know the formulas but how do I know when to use them?" is related to the previous blunder and is perhaps the commonest difficulty encountered in physics teaching. It is essentially a schizophrenic reaction —persons afflicted with schizophrenia are often beautifully facile on a verbal level, yet are completely at a loss on any more fundamental, nonlinguistic level. To a certain extent this fault is nurtured by the present tendency toward survey courses, one of whose aims seems to be to familiarize the student with the terminology of physical science. Thus, for purposes of many survey course examinations which I personally have seen, it is sufficient for a student to understand that the *word* "ampere" *is* a "coulomb" divided by a second. This habit of empty physical verbalization is a carry-over from other fields—everyday contacts and the like—where such modes of communication are very much the rule.[6]

[6] See, for example, T. Arnold, *The Folklore of Capitalism* (Yale Univ. Press, 1938).

3. Use of symbols whose structure does not correspond to that of the physical referent.—The usual crank letter in which the irate writer disproves conservation of energy is an excellent example. Very often the crank, not knowing anything about physics, will borrow symbols indiscriminately, throw them together, and turn out a result whose validity is nil because the structure of the original formulation was not similar to the structure of the physical facts to be explained.

4. Inability to extend the domain of a physical symbol.—I believe this fault is best illustrated by the many students who can understand the text but "can't work the problems," or by those who can solve problems in the book (where the setting for the symbols is essentially the same as the setting in which the symbols were first introduced) but cannot solve examination problems. In these cases the student fails to understand that physical symbols are presented elementalistically in textbook discussions, whereas physical reality is nonelementalistic and so defies any attempt to treat it completely with elementalistic symbols. If a nonelementalistic attitude toward symbols is adopted by the student—that is, if he is continually aware of the fact that not *all* aspects of a physical situation can be covered by a single symbol, and that what appears to be a single symbol "bites off" different chunks of reality in different contexts—he will gain a flexibility of viewpoint which is useful in overcoming this difficulty. As an example, I might point out that when a student first encounters the symbol "force," he is likely to take for the referent of the symbol some subjective feeling of muscular exertion. Later, when he studies Newton's laws, he may extend the domain of the symbol to include such nonanthropomorphic instances of "force" as frictional force, centripetal force, or the force exerted by a coiled spring. Still later, gravitational force, or, more generally, force in connection with fields of force, must be included among the referents of the symbol. While all of these referents have enough in common to be subsumed under the single symbol "force," they are, strictly speaking, distinct physical entities. The distinctions involved here are of the same type as those that arise in the application of a given symbolic formulation to a variety of different special problems; unless the student realizes that the same symbolism may refer to many physical situations, each slightly different from the other, he will be seriously handicapped in applying familiar symbols in unfamiliar contexts.

In these sketchy remarks I have tried to present an essentially new point of view on the general problem of why physics students "don't catch on." Admittedly, the analysis which I have given is incomplete; but it may serve to interest physics teachers in the semantic method of treating pedagogic problems so that they will work out other analyses and applications for themselves.

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Current Meetings

The spring meeting of the Pennsylvania Conference of College Physics Teachers will be held at Gettysburg College on March 31 and April 1. A session on Friday afternoon will be devoted to contributed papers, and will be followed by a dinner and an evening address. On Saturday morning there will be a symposium by speakers from the Army and the Navy.

The Southeastern Section of the American Physical Society is holding its annual meeting at the University of Georgia on March 31 and April 1. Teachers of physics for premedical students will be particularly interested in the symposium on biophysics which has been arranged. The guest speaker for the symposium is Dr. D. W. Bronk, Director of the Eldridge Reeves Johnson Foundation for Medical Physics, University of Pennsylvania.

Society and the Intelligent Physicist*

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A PHYSICIST cannot spend his life in the laboratory constantly striving to get the right answer, checking every idea against the inexorable requirement that it shall work, without something happening to his general outlook. Some of the points of view that he thus acquires react on his social impulses and behavior and on his understanding of what social conduct involves. We shall consider some of these here.

I think that the physicist comes to appreciate more vividly than anything else that the game of getting the right answer is a hard game, and that if he is going to be successful he must exert to the utmost all the intelligence he possesses. The only thing in his control by which he may command the situations which confront him is his intelligence, and even this is often enough not sufficient. When he is not successful he knows the reason is that he has not been intelligent enough, and he strives to realize his potentialities for greater intelligence. Furthermore, he comes to appreciate that the *utmost* exercise of intelligence means the *free* use of intelligence; he must be willing to follow *any* lead that he can see, undeterred by any inhibition, whether it arises from laziness or other unfortunate personal characteristics, or intellectual tradition or the social conventions of his epoch. In fact, intelligence and *free* intelligence come to be synonymous to him. It becomes inconceivable that anyone should consent to conduct his thinking under demonstrable restrictions, once these restrictions had been recognized, any more than as an experimenter he would consent to use only a restricted experimental technic. He finds often enough, as his experience grows, that as a matter of fact he has been operating under hampering restrictions, of which he had not been previously conscious. He also finds, if he wants to be confident of the foundations on which he builds intelligent action, that these foundations must have passed his own scrutiny. He honors no statement or procedure that does not offer at least the possibility of being checked by himself, and when he accepts authority, as he often must, it is merely in the spirit of saving himself time. He finds it difficult to avoid ascribing to results thus accepted on authority a somewhat smaller degree of probability than he does to results checked by himself.

The physicist presently becomes aware that merely good intentions or trying as hard as he can are not adequate to secure intelligent action, but that there is a technic of being intelligent which itself can be acquired only by the exercise of intelligence. The realization that there is a technic of being intelligent and that this technic can be acquired only by seriously taking thought unto oneself has been slowly dawning on the physicist since perhaps the beginning of the century. As everyone knows, the dawning of this realization has been accelerated by the discovery of many unsuspected phenomena in the realm of very small things that could not be fitted into the edifice of knowledge without important modifications in ways of looking at things which hitherto had proved good enough.

The physicist has thus come to be conscious of the existence of his intellectual tools, and has discovered that these tools have properties which he had not suspected. He observes that his own intellectual tools were acquired in school mostly by imitating the use of these tools by other people. He saw that these tools were used in certain kinds of situations in order to achieve certain purposes. He observed the success of others in using the tools to attain their purpose, and he presently verified by experience that he too could use the tools with success in similar situations. There thus arose a feeling of what his tools were good for, which was a compound of the opinion of others and the opinion of himself derived from successful use; but there was no serious attempt at analysis as to whether these assumptions were really valid, or what might be their range of validity if their validity was not

* This address, prefaced by some informal remarks, was given by invitation at the eighth annual meeting of the American Association of Physics Teachers. It contains essentially the subject matter of the author's book, *The Intelligent Individual and Society*.

universal. But presently, after much experience, analysis of what he did in using his tools disclosed that often his tacit assumptions as to their validity were not quite right. He came to see, for instance, that the complete sharpness and certainty which tradition ascribes to the conclusions of mathematics and logic were ultimately illusory. He found that he could always carry his analysis back to the point where certainty vanishes, for the reason that he always has to assure himself that he is correctly performing his own mental operations, if for no other reason. The need for continually checking his own procedures is perhaps something carried over from the laboratory by the physicist, and appears not to be felt so vividly by the mathematician or the logician. Mental processes not being absolutely sharp, it follows that our mental success can be only an approximate success, just as any measurement or adaptation of the laboratory is approximate. Partly, but not entirely, because of this lack of sharpness, it comes about that we often try to give meanings that cannot be given and to do things that cannot be done. We invent all sorts of absolutes and abstract existences, and find that we are mistaken about what we can do with them. The physicist discovers that he is a welter of urges which have only a historical or perhaps physiological significance, and he feels under no compulsion to honor them in his endeavor to get the right answer. For example, we discover that there are unsuspected infelicities in the way we have to deal with time. It was a shock to most physicists, and other people too, to discover that the time of experience does not have the property of absolute simultaneity that we had thought. Or we think it means something to talk about the "reality" of the past, and are helpless when we discover that there is no way of proving that the entire universe was not created five minutes ago. Or when it comes to a showdown, that is, application to concrete instances, we discover that we cannot mean by truth what we had thought we mean or what we want to mean. Or the idea of causality, which has been considered by many to be so fundamental that thinking could not be done without it, proves not to be applicable in the way we had thought in the realm of very small things now becoming accessible to experiment. Or there is a new and striking example: At temperatures close to absolute zero, liquid helium has readily measurable properties, such as fluidity, which at present can be treated only with that form of quantum theory which denies the property of individuality to the atoms. It is hard to think of anything more paradoxical than a particle to which the idea of individuality does not apply.

Out of all this experience one conclusion emerges perhaps more clearly than others; namely, there is no inherent presumption that ways of handling things or ways of thinking which have grown up to meet a certain range of experience and which have proved their validity within that range will continue to be valid when the range is extended. As a matter of fact, the range is continually being extended by the discovery of new experimental phenomena, made possible by the development of new experimental technics for controlling higher temperatures or higher voltages or higher vacuums, for example, or by greater precision of measurement. An example of this that even yet has not got itself completely assimilated into everyday thought is the new properties of matter moving with speeds which approach the speed of light. Because of all this the physicist has come to *expect* that he will have to change his way of thinking about things when his range is very much increased.

In analyzing what has happened when he has had to revise his concepts to meet new ranges of experience, he has been struck by the fact that different operations which gave the same result in the original range no longer give the same result when the range is extended. For example, the length of a moving streetcar is the same whether it is measured by taking an instantaneous photograph of it and properly measuring the photograph, or by boarding the car with a meter stick and measuring the length with the meter stick in quite the conventional way while it is in motion. But there is every reason to think that if the same two operations were performed on some object moving with a speed approaching that of light the results would be different. The physicist recognizes here an important characteristic of his thinking; namely, the impulse to simplify procedures by giving the

same name ("length" in this example) to recognizably different operations when these different operations lead to the same result. But he also recognizes that there is concealed here a grave potential danger in assuming that the equivalence of these two operations will continue to hold when the range of experience is extended. One may describe the situation in language suggested by quantum theory: Our ordinary concepts are multiply degenerate in the range of ordinary experience, and this degeneracy is revealed by separation into different levels when the range of experience broadens.

With all this experience, merely hinted at above, it is natural that the physicist should presently begin to wonder what the applications are to his social relations. For one of the impulses that he has acquired from his physical experience is to treat things as a piece; and since the problem which confronts him in many social situations is at bottom no different from that which confronts him in the laboratory, namely, to get the right answer, he wonders whether some of the lessons of his physical experience will not carry over into the social domain. He is the more inclined to make this application because he has found that the sorts of consideration which are becoming necessary for his understanding of physics are edging over, more and more, in directions pointing toward the problems of everyday life. For example, in understanding quantum theory he has to analyze what he means by the act of observation, or whether it is possible, and what it means, to divide the universe into an observer and the observed—considerations that get much closer to what he has, perhaps, called "philosophy" than he had at one time supposed.

This attempt of the physicist to enter the field of social thinking is very modest and unpretentious, and does not involve the assumptions that people are sometimes inclined to suppose and that lead them to view this attempt with something approaching resentment. There is not involved here any thesis that the methods of quantitative measurement of physics are applicable to the "social sciences," nor is there any thesis that "science" is competent to decide between values. All that the physicist wants in his modest way is that his actions as a social being be intelligent. He has seen things go wrong so often when intelligence was not exerted, and his drive to intelligence acquired in his laboratory is so powerful, that he insists on the exercise of intelligence in his social activities as no less essential than any of the many other things without which social existence would not be tolerable.

The preliminary to the exercise of social intelligence is the same as the preliminary to every exercise of intelligence in the laboratory; namely, searching analysis to discover everything that can be seen in the situation, and then, after everything has been dragged out into the light of day with no reservations whatever, discussion of what course of action is best fitted to produce the desired result. The desired result may perhaps be dictated solely by considerations of value; these may not be argued, but can only be accepted by intelligence as one of the conditions of the problem set for it to solve.

It is something of a shock to the enthusiastic and unsophisticated physicist who thus rushes to the social attack to discover how very often the practices and demands of society are positively inimical to the exercise of intelligence. Most people do not like to think beyond a certain point; the primary demand is not for the most effective social action, but merely for one that is acceptable, and if conventions which secure sufficiently acceptable action are already in force, any attempt to make inquiries which might lead to modification of that action is likely to be received with impatience, to say the least. The individual, after sufficient experience, comes to see this and learns to suppress the impulse to follow certain lines of argument or inquiry which he sees will not be well received by his fellows. It does not take the child long to learn that he cannot say, when his Sunday School teacher calmly assumes that of course he will want to be good, "But you cannot *make* me want to be good," and he keeps his mouth shut. Everyone knows that harmonious living together requires the exercise of good will, and good will is often incompatible with following every argument to its logical conclusion. If any proof is needed of this it will be afforded presently by the way you will find yourselves reacting to various things that I shall say. Although the

result of such exercise of good will is a society in which open friction has disappeared, nevertheless the method by which this desirable result is attained too often involves an element of intellectual surrender on the part of the individual which discourages future impulses toward intelligence in his social relations, and which, under proper conditions, may be fraught with sinister potentialities.

The physicist sees that not only are there unusually great opportunities for the suppression of intelligence in social thinking but that the need for intelligent thinking is even greater than in physics, because there is much greater chance that those requirements which he has found the technic of straight thinking demands will not be met. He sees this when he reflects on the way in which he acquired the concepts he uses in his own social thinking. These concepts, even more than those of physics, he usually acquired imitatively from his fellows while he was still too young to subject them to any critical analysis, and while he was still under the immediate necessity of finding some solution of the problem of the adaptations demanded by daily life. It was almost inevitable that he should merely assume that the ordinary social concepts could be used for the purposes for which he saw his fellows using them. But presently he comes to suspect that his fellows have never critically examined the concepts any more than he himself has but that they too acquired them when they were too young to reflect, and have been satisfied if they were decently effective in doing what was wanted of them. Although his fellows assume an unlimited validity for their social concepts, he becomes actively skeptical toward this assumption when he observes that other peoples with different backgrounds of tradition and different present purposes may not recognize the validity of these ideas at all, as the Japanese and the Germans apparently do not recognize the validity of moral ideas which an uncritical outlook insists are universal. He sees in all this an exemplification of what his physical experience has taught him; namely, ideas are to be suspected and reexamined when the domain of application is extended beyond that in which they arose. In one very important respect he recognizes that the present epoch differs from former epochs in that the enormous increase of invention, bringing peoples nearer together and increasing their command over forces both advantageous and disadvantageous to man, effectively provides just that extension in the domain of application of social concepts which he is prepared to expect would demand fundamental revision.

He is struck by the fact that, on the social level, the handling of language requires much greater caution and conceals much greater dangers than on the level of physics. On the social level, language plays a deliberately dual role: it is not only a rational tool adapted to describe and analyze factual situations, but it is also used to affect and control the actions of people. There is no necessary connection between these two functions of language, particularly since most people are not by instinct notoriously rational and do not demand a rational appeal to be stirred to action. Hence in many cases the presumption is that if language is adapted to one role it will not be adapted to the other. The distinction between these two roles is, however, almost always overlooked; and the general feeling seems to be that all and any language, except such as is obviously and intentionally poetic or esthetic, must be applicable on the factual plane. Whence arise great confusions, supernaturalisms and mysticisms of various kinds. The number of cases proves to be distressingly great in which our verbalisms never get down to the factual plane at all, in spite of the fact that we want them to and think they do. So we have open verbal chains, the meaning of one verbalism being expressed in terms of another verbalism, with never emergence into something that we do or that happens to us. This cancerous tissue of open verbal chains infests much of our social thinking.

Social thinking particularly exploits the intellectual device of giving the same name to recognizably different things when these things are equivalent in the limited range of use which is of most importance to us. In this way a great simplification of thought is often accomplished; to bring about a simplification in this way may constitute an intellectual invention of the first rank. But there is also danger in this exercise of intellectual invention, as already suggested, because we are likely to be caught unaware when

an extension of experience dissolves the equivalence of the different things which we had fused under a single name. The only defense is an analysis that recovers and emphasizes the complexities of the original situation, instead of discarding them.

The supreme social invention, I think, is to be found right here in a very broad type of situation in which we use a single name and ignore differences that are patent on consideration. Perhaps the earliest social lesson I learned was to say that my playmate was another person just like me, with feelings just like mine, which, therefore, were entitled to equal respect. What does it mean to say that the feelings of my fellow are the same as my own? How can I assure myself that his sensations in the presence of a hot object are the same as mine, and how can I be sure that a hot object does not feel to him as a cold object feels to me, and vice versa? Neither he nor I can find words to describe our feelings to the other which are of the slightest help. I can propose various tests, such as that he put up his right hand when he feels a hot object, and his left hand when he feels a cold one; but this avails only to show that he knows when he is in the presence of a hot object as distinguished from a cold one, and has no relevance to the question of what his feelings really are. After we have played with this situation long enough we come to see that we cannot possibly make our statement that his feeling of hot is the same as mine mean what we wanted it to. The statement is meaningless in the desired sense, and there is no way of getting the desired sense into it. My feeling of hot has a different meaning from my fellow's feeling of hot because what I do to decide whether I have the feeling of hot is different from what I do to decide whether my fellow has the feeling of hot. Anyone who reacts to this situation by saying that we cannot *prove* that his feeling of hot is the same as mine, but that all we can have is a greater or less degree of probability, has entirely missed the point. It does not make sense to think of his feeling and my feeling in terms such that this desired property of "sameness" is applicable. The only meaning which we can give to the statement that his feeling is the same as mine is that, in similar situations, his verbalizations and other reactions are the same as mine.

The social advantages of this invention of saying that my fellow has feelings exactly like mine are so obvious that it is hardly necessary to elaborate them. Because of it the actions of my fellows take on a certain measure of understandability and predictability. I can foresee what will please or displease them, and I can therefore influence their actions to a certain extent, so that I can plan my future with a certain amount of assurance; and, if I desire it, I can even attain to a certain degree of smooth cooperation with my fellows. This invention is the necessary background of the golden rule. Yet, in spite of the indispensability of the invention, I believe that its misuse is at the root of the most serious of our social difficulties and maladjustments. Its misuse consists in forgetting that it has a strictly limited field of applicability and of meaning. For it is evident enough that there is another side to all this. I am separated from my fellows by an impassable chasm, a chasm so impassable that even meanings cannot be the same on the two sides of it, in spite of my passionate desire. My pain and your pain, my pleasure and your pleasure, my thoughts and your thoughts, my death and your death, are irreconcilably different and can be made to fuse only by ignoring the obvious. Yet most of the conventions of society and of language itself are erected on a purposeful disregard of the difference. In fact, so deeply is the assumption of the equivalence of me and thee woven into the texture of language that, if my fellow does not see the difference for himself, it is almost impossible to make him see it, as I have found by many vain attempts.

The reason that the consequences of disregarding the difference between me and thee are important is that I see, and I presume that you see also, that the difference between me and my fellows is the most outstanding feature in my whole landscape. Society, by ignoring it and suppressing, even forcibly, the impulse of the individual to say what he sees, thus comes to be founded on a falsehood to which the individual must adapt himself as well as he can. For the child knows and continues to know, although he soon finds that he had better not say it out loud, that no one can get inside him and make him want to be good. I know that my thoughts are

my own and that there is no way by which you can discover what my thoughts really are; in fact, you cannot make my "real thoughts" even mean what you would like. I know that the most cogent argument of mathematics or logic, although it come to me with the authority of the world's greatest masters, is powerless to touch me until something clicks inside me. I know that the most high minded moral motives leave me cold and uncooperative until I have accepted as my own the purposes back of the system of morals. I know that it is in my power to accept or reject any and every expectation and demand of society, and that furthermore, as a matter of fact, I do thus accept or reject many of the expectations of society. I know that often my immediate personal interests, and also my long range interests as far as I can see, are opposed to the interests of society. I know that often enough my purposes and ideals are not the same as those of my fellows, so that what seems good to me may not seem good to them. I know that any action of mine which is free and well considered —that is, intelligent—is dictated by what seems good to *me*, and if the action is one which is also to the advantage of society, it is because I have accepted the view of society. I can see these things and say these things, whether or not the things which seem good to me are socially good. I know that society can secure my *free* action only by making that action seem good to me, and that otherwise society can modify my action only by compelling me by the exercise or the threat of superior physical force. I know all these things are true of myself, and, in accordance with my social maxim that I can understand you in the light of my understanding of myself, my actions toward you must be guided by the conviction that you find them true for yourself also. Yet society does not recognize this in its appeal to me, but tries to get hold of me by absolutes and supernaturals and verbalisms.

When I analyze the method by which my fellows appeal to me to get me to act in a way that is socially acceptable, what do I find? Ideals of service and unselfishness are held up to me. Why should society expect that it can get hold of me by talking about the virtue of service and unselfishness if it should happen that the purposes and consequences of unselfish action do not seem good to me? It appears that the reason it is expected that I will respond to ideals of service and unselfishness is not that such ideals are harmonious with my nature and therefore good to me, but that it is my "duty" to accept such ideals. This "duty" is conceived as something eternal in the nature of things, completely external to my own poor self, in virtue of which I am under a compulsion to act as I "ought." It has been remarked before this by more than one cynical observer that it is a rather surprising coincidence, to say the least, that in so many cases what is thus specified to be my duty turns out to be for the ordinary material advantage of the average member of society, or of that class of society which has the power. The intelligent but unsocial individual sees the irrationality of all this, and the intensity of his scorn of society is doubled because society appears to him not only dishonest but stupid. Why should society be so calm in its assumption that I am like the average of my fellows, or that what is good for it will also seem good to me? Even if my fellows are all honest in contending that what seems good to them is also good for society, society cannot get inside me to know what really seems good to me; even if I say what seems good to me, they cannot be sure that I am not lying for fear of social pressure. I think my fellows would not so easily say that I am like the average of all of them if it were not for our fundamental invention of saying that your feelings are the same as my feelings.

I think that society, before it can become a fit abode for intelligent beings, has got to recognize that the individual will freely act in a socially acceptable way only if such action seems good to that individual. The only way it can alter the free acts of the individual, if it should be necessary to alter them for the advantage of society, is to modify by example or some other form of education what the individual accepts as his good. Since "society" means you and me, this means that I, in my capacity as a member of society, will not allow myself to appeal to my neighbor by some mystical argument which analysis proves to be for my own disguised advantage rather than his. I think that examination will show that this requirement would wipe out a surprisingly large fraction of the conventional ethical arguments.

The importance of clearly seeing that the intelligent individual will freely act only in the way which seems good to him should be particularly evident at the present time. If society were composed exclusively of members so constituted that what every individual accepted as his good was also for the good of the others, there would be no problem; I would not have to say the things I have just said, and you would not be saying to yourselves, "If I had as mean and unsocial a disposition as that fellow I would be jolly careful to keep it to myself." But it is obvious enough, particularly at the present, that not every man is by nature a social animal. If he is also intelligent he will act in an unsocial way if he has opportunity, and it is just silly to think that he can be got hold of by being shown the unsocial consequences of his actions. Hitler is *right* and intelligent in persecuting the Jews if the exaltation of the German race is for him a good; or he is right in exposing the world to the danger of war if war is for him a good, and the rest of us who sputter at him have just failed to be intelligent in expecting him to act according to a code that is for our advantage and against his. Hitler is right in despising the intelligence of people who expect him to be guided by motives which he hasn't got. One element of our failure to be intelligent in this situation consists in our mistaken appraisal of the factual situation. It was inconceivable to us that human beings should exist whose good differs by so much from what we conceive to be the normal as does Hitler's. It should now be obvious to all of civilization that human beings may be expected to appear every now and then whose good, either because of their nature or because of an unusual combination of circumstances to which they have been exposed, it matters not which, may diverge by any amount whatever from the norm. An intelligent society has got to be constructed on a recognition of this possibility.

The means that society must be prepared to take when this possibility is adequately recognized is connected with another of those inescapable properties of the world in which we live which is so obvious that it need only be said to command assent; namely, I am powerless in the face of overwhelming physical force. There is no argument with an exploding bomb. Furthermore, I often experience such overwhelming physical force in the concerted action of my fellows, and conversely, I see that sometimes I can so maneuver as to procure the application of an overwhelming physical force to my neighbor and thus secure from him the action which I desire. The recognition of all this is merely a recognition of the factual nature of my environment. I must count on my intelligent neighbor seeing all this; and if the exercise of force seems to him a good in itself, or if the exercise of force seems to him a lesser evil to be overbalanced by some greater good, then I must also count on his using force against me in his attempt to procure his ends. In reply to his action I have the choice of yielding without a struggle, or of attempting to meet his force by superior force of my own. There are people to whom the exercise of force against their neighbor, under any circumstances, is so repugnant that they would rather be exterminated than oppose force with force. Most people, however, do not seem to be constituted in this way. Although the exercise of force is intrinsically repugnant to them and, up to a certain point, they will yield or compromise to avoid the necessity for exerting force, nevertheless, beyond a certain point incompatibilities become too great, and they will fight. Sometimes people appear to find it necessary to justify their willingness to use force when incompatibilities become too great. It seems to me that no apology should be necessary, but willingness to use force beyond a certain point constitutes nothing more than clear-eyed recognition of the nature of the world about us. There is no more reason why I should hesitate to recognize this natural "law" any more than any other natural law, such as that I must keep my head above water if I wish to live. The physicist, particularly, who has spent his life adapting himself to the world about him, will, I think, have little inclination to apologize when he accepts the naturally imposed necessity to use force to secure desired results in certain situations.

Society in its relation to the individual is almost always, by virtue of its enormous superiority of numbers, in a position to exert, when it chooses, such overwhelming force that the individual can only yield. This possibility is always in the background, and constitutes an essential

element in the relation of the individual to society. An honest analysis of the situation demands that this be said out loud with frankness. But society is composed of you and me, and in its actions will reflect to a certain degree what seems good to you and me. If most of us dislike to use force, as seems to be the case, we expect that society will use force against the individual only as the last resort, when incompatibilities become so extreme that they can be handled in no other way. Such a society will first make every attempt to bring the individual to adopt freely a socially acceptable line of conduct.

If you and I are intelligent, we will want to have society a fit abode for intelligent beings, which means that, below the point at which we have to apply force, we will appeal to our fellow as an intelligent being, and will try to bring him to adopt freely, *because all things considered, it seems good to him*, that line of conduct which is also to the advantage of you and me. How great a modification this means in conventional social practice is evident enough. It will be a slow and difficult process that can be accomplished only by a long campaign of education extending over generations. The problem is to present to the individual all the relations and consequences of his actions, allowing the vision of *all* the consequences to modify his drives and what seems good to him, until in the end his drives are self-consciously stabilized in perfect accord with whatever his own nature may be. If, when his drives have been educated and stabilized, they are still antisocial, we must be prepared to restrain him by force. There is obviously a great gamble in such a program; you and I are gambling that the majority of our fellows are so constituted that when their drives have been educated a harmonious society is possible. Although we must always expect that there will be a certain number whose educated drives may be antisocial to any degree, we are gambling that there will not be so many of them that the rest of us cannot restrain them by force. That is, we are gambling that the human animal is so constituted that the race as a whole is capable of building up an intelligent society. I think many people are afraid to make this gamble—fear is back of a great deal of social conservatism. The more courageous course appeals to me; if man is not the kind of animal that can create for himself an intelligent society, I would rather not have any society at all.

Although Hitler may be right in following his own drives in the face of the abhorrence of a large part of his fellows, he is dead wrong if he thinks that an intelligent society can be created by suppressing the individual and turning the world into a human ant heap. An intelligent society has got to start with the individual and end with the individual. Nothing else makes sense.

Organizing a College Credit Course in Photography

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With the increasing application of photography in widely varying fields, and the rapidly growing interest in the subject on the part of students, there has come an urgent demand for courses in photography as a regular part of the college curriculum. Several colleges and universities have offered courses in photography for many years, and it is believed that other institutions will do so in the near future. This paper is presented in the hope of being of some assistance to instructors contemplating the organization of such a course.

Objectives

The objectives of a college credit course in photography will vary somewhat with the nature of the institution and the particular department offering the course. In general, however, it will be found that the primary objective is to develop a thorough knowledge of the scientific background and the fundamental technics of photography which the student will be able to put to practical use by applying scientific principles rather than by following rules of thumb.

Generally speaking, such courses are not concerned with the training of students in the practice of photography as a vocation and, therefore, do not include matters related to commercial practice. A thoroughly scientific course in the principles of photography has been found to be a useful elective for science majors and for students of engineering, medicine and education. It is a valuable addition to the programs of students of journalism and the fine arts. Frequently the class will contain students from several of the foregoing classifications, in addition to those who are in it solely because of personal interest. Consequently, the preparation and requirements of all groups must be taken into account in setting up the objectives of the course.

Organization

By its nature, a general course in the principles and practice of photography properly lies within the province of the physics department, and has been found to be a very worthwhile addition to the physics curriculum. As such it may serve two purposes: if open to students who have not had college physics, it often introduces them favorably to the activities of the department and induces them to take other courses in physics; and, when taken following a course in general physics, it presents many interesting applications of physical principles.

There is some danger that the physics instructor teaching a course in photography will, in his enthusiasm for his favorite subject, overemphasize the applications of physics as such. It must be borne in mind that the student is interested in learning the principles of photography for their own sake, and not merely as illustrations of physical principles.

As it is generally offered, photography is a one-semester course carrying two or three semester hours credit. With the extensive developments that have come about in the last several years, there is no doubt that the scope and rigor of a thoroughly scientific course in photography fully justifies offering it for three credits. A very satisfactory program consists of two lecture-recitation periods per week and a laboratory period of three hours. It will be found that two class periods per week for one semester will not be too much time to spend on the general theory and underlying principles of the subject. A genuinely scientific course in photography demands a considerable amount of analytic treatment, and draws upon the subject matter of physics, chemistry and mathematics. It affords an excellent opportunity for effective analysis under the stimulus of an interest in immediate practical applications. The laws of optics and the application of these laws to image formation, the radiation laws and their significance in photography, the physical and chemical properties of the silver halides with their relations to the characteristic behavior of the photographic emulsion, the nature of the latent image, and the physical and psychological aspects of color are but a few of the topics that emphasize the scientific nature of the subject. Depending upon the local objectives, the course may or may not have prerequisites. In some cases, one year of college physics is a prerequisite. Sometimes sophomore standing is required, but quite often the course is open to freshmen and has no college prerequisites.

Subject Matter

The essential subject matter of an introductory course in photography may be broadly classified as follows.

I. *Optics:* fundamental laws of optics; principles of image formation; perspective; simple lenses and their defects; compound lenses, with special attention to the photographic objective; photographic problems such as *depth of field, lens speed and angle of view.*

II. *Photographic equipment:* cameras of all types; general accessories; the darkroom.

III. *Making the negative:* characteristics of the photographic emulsion; exposure and the characteristic curve; development and the characteristic curve; chemistry of development; chemistry of fixation; processing procedures.

IV. *Orthochromatics:* the faithful representation of colored objects in shades of gray; color sensitivity of emulsions; filters and their uses.

V. *Making the positive print:* adapting the printing medium to the negative; contact prints; enlargements; transparencies; toning of prints.

VI. *Natural color processes:* general principles of color; additive color processes; subtractive color processes; positive prints in color.

VII. *General considerations:* history of photography; practical applications in science, medicine, photoengraving, etc.; aesthetics.

The foregoing outline is not intended to be inclusive but only to sketch broadly the general

outline of an introductory course. The sequence of subjects is open to considerable choice, and the course may begin almost equally well with Parts I, II or III. While perhaps the most logical beginning is with optics—since image formation is the first step in the photographic process—this order has two drawbacks. One lies in the difficulty of holding the interest of the student in a somewhat long and tedious development when he is eager to get on to what he regards as strictly photographic matters. The other drawback is that spending two or three weeks on optics makes it difficult to assign laboratory experiments for which the student is prepared, particularly if he has had no previous experience with a camera. For these reasons, some instructors like to begin the course with a study of cameras and their uses. Others prefer to begin with a study of the photographic emulsion, an approach that has the advantage of introducing the student at once to the essential problem of photography, namely, the perpetuation of the image; it leads directly to the effect of exposure and development upon the negative, and thus prepares the student for photographic practice in the laboratory. Notwithstanding the aforementioned difficulties of beginning with a study of optics, the author prefers to follow the order given here.

Textbooks and References

The teacher who is contemplating giving a course in photography may experience some difficulty in finding a textbook that meets his requirements. A survey of photographic literature shows that the available books in English may be divided rather readily into two classes: a large number of books of a very elementary character, written in nontechnical language and quite unsuited for use as college textbooks; and a relatively small number of advanced treatises, valuable as reference works but wholly unsatisfactory as general textbooks in an introductory course. Some few books have appeared that may meet the requirements of certain courses, and at least two new books written principally for use as college textbooks are soon to be published.[1] As is often the case, some instructors may want to draw from several sources, or to prepare their own syllabuses. For the benefit of such teachers, a list of books which the author has found most valuable is given.

[1] Mack and Martin, *The Photographic Process* (McGraw-Hill); Roebuck and Staley, *Photography* (Appleton).

Books

Angerer, *Wissenschaftliche Photographie* (Akademische Verlags Gesellschaft, Leipzig, 1931).

Bailey, *Photography and Fine Art* (Davis Press, 1922).

Barnard and Welch, *Photography and Fine Art* (Longmans Green, 1925).

Bayley, *The Complete Photographer* (Methuen, 1932).

Blair, *Practical and Theoretical Photography* (Pitman, 1938).

Clerc, *Ilford Manual of Process Work* (Ilford, London).

Clerc, *Photography, Theory and Practice* (Pitman, 1937).

Dalzell, *Practical Stereoscopic Photography* (Technical Press, London, 1936).

Davis, *Practical Amateur Photography* (Little, Brown, 1937).

Derr, *Photography for Students of Physics and Chemistry* (Macmillan, 1913).

Dunn, *Natural Color Processes* (Chapman & Hall, 1938).

Dutton, *Perfect Print Control* (Galleon Press, 1937).

Eder, *Ausführliches Handbuch der Photographie* (Wilhelm Knapp, Halle, 1906–1932).

Fanstone, *Colour Photography* (Pitman, 1935).

Groesbeck, *The Process and Practice of Photoengraving* (Doubleday Page, 1924).

Gillies, *Principles of Pictorial Photography* (Falk, 1923).

Hackleman, *Commercial Engraving and Printing* (Commercial Engraving Pub. Co., Indianapolis, 1924).

Hammond, *Pictorial Composition in Photography* (American Photographic Pub. Co., 1932).

Hay and von Rohr, *Handbuch der Wissenschaftlichen und Angewandten Photographie* (Springer, 1929–33).

Henney, *Color Photography for the Amateur* (McGraw-Hill, 1938).

Jordan, *Photographic Enlarging* (American Photographic Pub. Co., 1935).

Judge, *Stereoscopic Photography* (American Photographic Pub. Co., 1926).

Kepler, *The Eighth Art, Color Photography* (American Photographic Pub. Co., 1938).

Mees, *Photography* (Macmillan, 1937).

Neblette, *Photography, Principles and Practice* (Van Nostrand, 1938).

Neblette, Brehm and Priest, *Elementary Photography* (Macmillan, 1937).

Nelson, *Natural Color Film* (Galleon Press, 1937).

Newens, *The Technique of Color Photography* (Blackie & Son, 1936).

Newhall, *Photography 1839–1937* (Museum of Modern Art, New York, 1937).

Nietz, *The Theory of Development* (Van Nostrand, 1922).

Rawlings, *Infra-red Photography* (American Photographic Pub. Co., 1934).

Sheppard, *Gelatin in Photography*, 2 vol. (Van Nostrand, 1923).

Simpson, *Composition for Photographers* (Witherby, London, 1937).

Snodgrass, *Science and Practice of Photographic Printing* (Falk Pub. Co., 1931).
Spencer, *Colour Photography in Practise* (Pitman, 1938).
Spencer, *Photography Today* (Oxford Univ. Press, 1936).
Taft, *Photography and the American Scene* (Macmillan, 1938).
Tilney, *Principles of Photographic Pictorialism* (American Photographic Pub. Co., 1930).
Trivelli and Sheppard, *The Silver Bromide Grain of Photographic Emulsions* (Van Nostrand, 1921).
Verfasser, *The Halftone Process* (Iliffe, London, 1904).
Wall, *Photographic Emulsions* (Chapman & Hall, 1929).
Wall, *The Photographic Dark Room* (American Photographic Pub. Co., 1933).
Abridged Scientific Publications, several volumes (Eastman Kodak Co. Research Laboratories).
Basic Photography (U. S. Air Corps, War Dept., 1930).
Encyclopedia of Photography (American Photographic Pub. Co., 1938).
The Leica Manual (Morgan and Lester, 1938).
The Photography of Colored Objects (Eastman Kodak Co., 1933).
Elementary Photographic Chemistry (Eastman Kodak Co., 1936).
Photography as a Scientific Implement, a collective work (Blackie & Son, 1923).

Periodicals

American Photography, monthly (American Photographic Pub. Co., Boston).
American Annual of Photography, annually (American Photographic Pub. Co.) Contains useful tables and formulas as well as miscellaneous articles.
British Almanac, annually (Henry Greenwood & Co., London).
British Journal of Photography, monthly (Henry Greenwood & Co., London).
Camera, monthly (Frank V. Chambers, 636 S. Franklin Sq., Philadelphia).
Camera Craft, monthly (Camera Craft Pub. Co., San Francisco).
The Photographic Journal Including Transactions of the Royal Photographic Society, published monthly (Royal Photographic Society of Great Britain, London).
The Photo Miniature. A series of monographs published monthly (Tenant and Ward, New York).
Popular Photography, monthly (Ziff-Davis Pub. Co., Chicago).

Laboratory Work

An essential part of the photographic course is the laboratory work. In cultivating an appreciation of the experimental method, and in developing manipulative skill, the laboratory work in photography is on a par with that of any other elementary science course. The experiments should be selected and written up with the double objective of giving the student firsthand acquaintance with the application of physical principles, and of training him in the practice of essential photographic technics. In a three-credit semester course a student may be expected to perform from 12 to 20 experiments. A suggested list for an introductory course follows.

1. Elementary processing procedures; developing and printing
2. Pinhole photography
3. Focal length, angle of view, image size
4. Perspective studies
5. Study of exposure; latitude
6. Development and contrast
7. Constituents of a developer
8. Copy in black and white
9. Orthochromatic study
10. Contrast filters
11. Positive prints; adapting paper to negative
12. Projection printing
13. The characteristic curve
14. Intensification and reduction
15. Toning
16. Lantern slides
17. Infra-red photography
18. The polarizing screen
19. Lens quality
20. Shutter test
21. Photomicrography
22. Direct color transparency
23. Color separation negatives
24. Three-color printing

The experimental work may be conducted most satisfactorily in a regularly scheduled laboratory period of two or three hours. This plan, however, calls for sufficient equipment and darkroom facilities to accommodate a number of students at once. There should be at least one darkroom for each four students in a laboratory section. When laboratory and darkroom facilities are limited, it has been found possible to carry on the experimental work in less formal manner by assigning projects in advance and permitting students to carry them out at their own convenience, making darkroom reservations when necessary. In this manner, one darkroom can be made to serve about 12 students, and the physics laboratory does duty as a photographic laboratory. Obviously, such an arrangement does not permit as much supervision on the part of the instructor as does a regular laboratory period, and should be supplemented by conference periods. It does not demand as many cameras, and as much accessory equipment, since fewer students are working at a time, and apparatus is checked out as needed.

The fee problem may be handled in any of three ways: (a) a laboratory deposit may be required, against which the purchase of supplies is charged, the maximum possible refund being based upon a fixed charge for laboratory operation; (b) a minimum laboratory fee may be charged, based upon the use of laboratory facilities, the student purchasing his own photographic materials either through the department or otherwise; or (c) the laboratory fee may include the cost of a predetermined list of supplies, beyond which the student is expected to make such purchases as he finds necessary. The first plan is least satisfactory in most cases because of the bookkeeping that it requires. Procedures (b) and (c) are equally satisfactory, the choice depending upon the particular business arrangements in the institution concerned. A suggested list of supplies to be issued, or sold, to the student at the beginning of the course is:

1 doz nonchromatic cut film, $3\frac{1}{4}\times4\frac{1}{4}$ in.
1 doz orthochromatic cut film, $3\frac{1}{4}\times4\frac{1}{4}$ in.
1 doz panchromatic cut film, $3\frac{1}{4}\times4\frac{1}{4}$ in.
2 doz sheets contact printing paper, $3\frac{1}{4}\times4\frac{1}{4}$ in.; low contrast, No. 2 or No. 3
2 doz sheets contact printing paper, $3\frac{1}{4}\times4\frac{1}{4}$ in.; high contrast, No. 4 or No. 5
1 doz sheets projection paper, 8×10 in., medium
1 doz sheets projection paper, 8×10 in., contrast

Small quantities of special materials such as process film, infra-red plates, lantern slide plates, and materials for natural color processes may be provided as needed. A general list of photographic supplies required for class use appears at the end of this article.

Physical Equipment

Perhaps the most urgent problem confronting the instructor who is planning a course in photography is the matter of physical equipment. In this connection it may be stated that the necessary investment in equipment for a one-semester course is considerably less than that for most laboratory science courses of equal scope. While a completely equipped photographic laboratory may represent considerable investment, the minimum requirements are surprisingly small.

The first item to be considered is that of laboratory space, the principle feature of which concerns suitable darkroom facilities. The ideal arrangement for a photographic laboratory consists of a sizeable main room for general experimentation with several darkrooms opening off it. The laboratory should be equipped with a preparation desk provided with running water. It should contain individual student lockers for the storing of personal equipment, as well as adequate storage space for departmental equipment and supplies. One wall should be kept clear and suitably painted for use as a background. Bookshelves, bulletin boards, and display cabinets for prints and transparencies should be provided. It is desirable that the laboratory be equipped with darkening shades.

The individual darkrooms need not be large—5×8 ft is sufficient for two students working together—but they should be provided with adequate ventilation. Each darkroom should contain a sink with hot and cold water. A mixer-type fixture is a great convenience since it enables running water to be used at any desired temperature. At least two electrical outlets are needed. Suitable equipment for each darkroom consists of the following:

1 safelight equipped with 1 yellow and 1 red filter	1 graduate, 500 ml
	1 graduate, 250 ml
1 contact printer, 5×7 in.	2 beakers, 1000 ml
1 print trimmer, 12 in.	1 plate drying rack
1 timer	12 drying clips for cut film
6 enamel trays, 4×5 in.	1 print roller, 8 in.
1 camel's hair brush	2 ferrotype plates, 18×24 in.

Special equipment such as developing tanks for miniature film, large trays for enlargements, etc., may be issued as needed.

In addition to the small individual darkrooms, a somewhat larger one should be equipped as an enlarging room for general use. It is well to have this enlarging room provided with both a miniature (35 mm) enlarger and one that will handle negatives up to 5×7 in. The construction of a very suitable enlarger for general work is a simple project for any physics department.

In equipping a photographic laboratory, the first consideration is the selection of cameras for experimental work. The student camera must be a general-purpose camera adaptable to a variety of photographic problems. It must be compact, sturdy and durable. The writer has found the most satisfactory type for general student use to be the combination plate, cut film and film-pack

camera, such as the Eastman *Recomar*, Zeiss *Maximar*, Voightlander *Bergheil*, and many others of similar design. An essential feature of these cameras is the double-extension bellows, which makes them suitable for copying and for photographing near-by objects. Their adaptability for both plates and cut film is an advantage in experimental work. They are provided with focusing back, rising and falling front and, usually, lateral movements of the lens carriage. Cameras of this type are available in two popular sizes, $2\frac{1}{4}\times 3\frac{1}{4}$ in. (also 6.5×9 cm) and $3\frac{1}{4}\times 4\frac{1}{4}$ in. (also 9×12 cm). While the smaller size is somewhat more economical to use and entirely satisfactory so far as the negative size is concerned, the author recommends the $3\frac{1}{4}\times 4\frac{1}{4}$-in. size because it is a universal standard; equipment of all kinds is available for it. Moreover, since the standard lantern slide plate is $3\frac{1}{4}\times 4$ in., developing tanks, fixing tanks and washing boxes for plates and cut film can be used for processing lantern slides. A fast lens is not required; a fairly good anastigmat with a speed of $f:4.5$ is quite satisfactory. A reliable shutter that can be set for "time" and "bulb," and with fixed exposure times from 1 to 1/300 sec, is desirable. An important requirement of the shutter is that it be fairly rugged.

Each camera should be supplied with six combination plate-film holders, cable release, filter holder, lens shade, tripod and carrying case. The carrying case will be found to pay for itself in reduced wear and tear on the camera and in prevention of loss of accessories. The tripod should be light but rugged; the moderately priced wooden type is best.

The type of camera described here, while ideal for most student purposes, has one limitation from the standpoint of experimental work; namely, it is not adapted to the ready interchange of lenses. It is well, therefore, to have one camera of the type known as the "view camera," which has a removable lens board. A further advantage of this camera is that it is provided with swing adjustments, which make it suitable for experiments in perspective and depth of field. The view camera should be equipped with three lenses of wide, normal and narrow angle. A convertible lens in which the elements may be used separately or together is a very useful accessory for studies on angle of view, image size and focal length.

TABLE I. *Desirable and minimum laboratory equipment.*

	(A)	(B)
Darkrooms	4	2
Student cameras and aforementioned accessories	5	2
View camera or Speed Graphic, $3\frac{1}{4}\times 4\frac{1}{4}$ or 4×5 in.	1	1
Miniature camera with standard lens	1	0
Lens, 6 in. anastigmat in shutter (for use with view camera)	1	0
Lens, $3\frac{1}{2}$ in. (wide angle) in shutter	1	1
Lens, 12 in. anastigmat in shutter	1	0
Lens, convertible	1	1
Photoelectric exposure meters	2	1
Enlarger, 4×5 or 5×7 in., with lens	1	1
Enlarger, miniature	1	0
Contact printers, 5×7 in.	4	2
Safelights	4	2
Trays, enamel, 4×5 in.	24	12
Trays, enamel, 8×10 in.	6	3
Print rollers, 8 in.	4	1
Timers	4	2
Print trimmers, 12 in.	4	2
Graduates, 500 ml	4	0
Graduates, 250 ml	4	2
Ferrotype plates, 18×24 in.	12	6
Lantern slide washing box	1	1
Developing tanks, stainless steel	2	1
Fixing tanks	2	1
Cut film drying clips	24	12
Cut film hangers	24	12
Printing frames, 5×7 in.	2	1
Printing frames, 8×10 in.	1	1
Reflector lighting units	2	2
Chemical balance	1	1
Print tongs	4	0
Filters* Wratten A, B, C5, K1, K2, X1, X2, G	2 each	1 each
Polarizing screens	2	1
White blotters, sponges, filter paper, funnels, beakers, thermometers, and miscellaneous equipment from the physics laboratory.		

* Satisfactory filters can be made by cementing gelatin filters between 2-in. squares of lantern slide cover glass.

Another camera which is very suitable for experimental work is the *Speed Graphic*, manufactured by the Folmer Graflex Corporation. In addition to a long bellows extension, rising and falling lens carriage, and removable lens board, this camera has a focal plane shutter, which is useful for fast exposures (up to 1/1000 sec) and for experiments upon image deformations characteristic of the focal plane shutter. The *Speed Graphic* is much more expensive than the cameras listed as suitable for general student use. While it is not an essential part of the equipment, one such instrument is a valuable addition to the laboratory. Where ample funds are available it is

also desirable to have one of the modern precision miniature cameras such as the *Contax* and the *Leica*.

In addition to the cameras, numerous other items are required for the performance of laboratory experiments. The amount of equipment needed for a class of a given size depends upon the manner of conducting the work, and it is difficult to make general recommendations. A suggested list of equipment for handling a laboratory class of from 12 to 16 students in one laboratory period is given in Table I in terms (A) of what is desirable for most efficient work, and (B) the minimum equipment with which such a course could be started.

TABLE II.

Nonchromatic film	24 boxes (1 doz ea.)
Orthochromatic film	24 boxes (1 doz ea.)
Panchromatic film	48 boxes (1 doz ea.)
Process film	12 boxes (1 doz ea.)
Process panchromatic film	6 boxes (1 doz ea.)
Infra-red plates	4 boxes (1 doz ea.)
Dufaycolor film	8 boxes (6 ea.)
Lantern slide plates (normal)	4 boxes (1 doz ea.)
Lantern slide plates (contrast)	4 boxes (1 doz ea.)
Contact paper, glossy, No. 1	6 pkg. (2 doz ea.)
Contact paper, No. 2	24 pkg. (2 doz ea.)
Contact paper, No. 3	6 pkg. (2 doz ea.)
Contact paper, No. 4	24 pkg. (2 doz ea.)
Contact paper, No. 5	6 pkg. (2 doz ea.)
Projection paper, soft	3 pkg. (1 doz ea.)
Projection paper, medium	24 pkg. (1 doz ea.)
Projection paper, contrast	24 pkg. (1 doz ea.)
Projection paper, extra contrast	3 pkg. (1 doz ea.)
Photoflood bulbs, No. 1	12
Lens paper	2 pkg.
Hypo, crystal	15 kg
Hydroquinone	500 gm
Metol	200 gm
Potassium bromide, crystals	250 gm
Sodium sulfite	5 kg
Sodium carbonate	5 kg
Potassium chrome alum, crystals	500 gm
Potassium oxalate, neutral	500 gm
Sodium sulfide	500 gm
Potassium bichromate, crystals	250 gm
Amidol	250 gm
Catechol	100 gm
Paraphylene diamine	100 gm
Glycin	100 gm
Silver nitrate	100 gm
Gold chloride	5 gm
Thiourea	100 gm
Potassium ferricyanide	500 gm
Ammonium nitrate	500 gm
Potassium metabisulfite	100 gm
Sodium hydroxide	250 gm
Ammonium persulfate	250 gm
Boric acid, crystal	100 gm
Acetic acid, glacial	5 liters
Formalin	1 liter
Glycerin	1 liter
Borax	1 lb box

PHOTOGRAPHIC SUPPLIES

In addition to the permanent equipment, a stock of photographic supplies must be kept on hand. These consumable supplies consist of photosensitive materials and photographic chemicals. While the variety of available photosensitive materials is very large, it is possible to reduce the essential requirements to a relatively few which are representative of their types. Cut film is the most satisfactory negative material for most purposes. It is compact, unbreakable, easily handled and available in a wider variety of emulsions than any other negative material.

For experimental work it is necessary to have at least one typical nonchromatic (improperly called "color blind"), one orthochromatic, and one panchromatic emulsion. The type of film known in the trade as *commercial* is a very satisfactory nonchromatic film. Typical orthochromatic materials are Eastman *Ortho Press*, Agfa *Plenachrome* or *Super Pleno Press*, and Defender *XF Ortho*. Any of the modern panchromatic materials such as Eastman *S. S. Panchromatic*, Agfa *Superpan*, or Defender *XF Panchromatic* are suitable for maximum color correction, and are well adapted for general student use. In addition to the foregoing three types of film, the negative stock should include process film and panchromatic process film for copying purposes, and infra-red plates.

The printing materials should include contact paper in several contrast grades, projection paper in at least two grades, and lantern slide plates, normal and contrast. The chemical stock should contain an adequate supply of all chemicals ordinarily used in developing, fixing, hardening, intensifying, reducing and toning.

An estimated list of photosensitive materials and chemicals for a one-semester class of 20 students is given in Table II.

CONCLUSION

On the grounds of student interest, practical application and academic value, the introduction into the college curriculum of a credit course in photography is fully justified. The laboratory discipline compares favorably with that of any other experimental science. The physical requirements are not prohibitive, being less than the minimum for most elementary science courses.

In this article the author has attempted to sketch in broad outline the essential considerations involved in the planning of an introductory course in photography. Because of the great diversity of circumstances, the suggestions made have had to be quite general, and estimates are based upon a hypothetical course which will probably not be exactly duplicated anywhere. No estimates of costs have been given because such figures are subject to wide variation, and more accurate judgment can be made by the instructor in the light of individual circumstances and requirements. The author will be pleased to communicate with anyone concerning details not covered in this paper. Acknowledgement is made of many helpful suggestions received from the writer's colleague, Professor Julian E. Mack, and from Professor Manfred Olson of Milwaukee State Teachers College.

Reproductions of Prints, Drawings and Paintings of Interest in the History of Physics

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5. Portraits and Caricatures of Joseph Black, and Prints of Edinburgh and Glasgow in His Day

JOSEPH BLACK (1728–1799) not only laid the foundations of the quantitative science of heat and in so doing helped his most famous pupil, James Watt, to the invention of the condenser which made the steam engine really efficient, but by proving the existence of a gas distinct from air and by his appeal to the balance (in this he anticipated Lavoisier), he became one of the founders of scientific chemistry. His work was thus a connecting link between science and industry, and a foundation stone of both physics and chemistry. He did this by extending exact quantitative measurements—which previously had been applied largely to mechanics—to heat and chemical combinations as well. Born the year after Newton's death, he made his discoveries in heat about 1760 when he was just over thirty years of age and while he was Professor of Chemistry at the University of Glasgow.

An excellent portrait of Black by Sir Henry Raeburn hangs in the University of Edinburgh. It has been often reproduced. The crayon drawing in the Scottish National Portrait Gallery, Edinburgh, is less well known. Along with these portraits it is interesting and useful to have the following word picture painted by Black's pupil, colleague and friend, John Robison, Professor of Natural Philosophy in the University of Edinburgh. It is quoted from "The Editor's Preface" to *Lectures on the Elements of Chemistry, Delivered in the University of Edinburgh; by the Late Joseph Black, M.D.* These lectures, published in 1803, after Black's death, were written out by Robison from Black's own notes, supplemented by those of some of his students.

"When I was first acquainted with Dr. Black, his aspect was comely and interesting. As he advanced in years, his countenance continued to preserve that pleasing expression of inward satisfaction, which, by giving ease to the beholder, never fails to please. His manner was perfectly easy, and unaffected, and graceful. He was of most easy approach, affable, and readily entered into conversation, whether serious or trivial. His mind being abundantly furnished with matter, his conversation was at all times pertinent and agreeable: For Dr. Black's acquirements were not merely those of a man of science. He was a stranger to none of the elegant accomplishments of life. He therefore easily fell into any topic of conversation, and supported his part in it respectably. He had a fine or accurate musical ear, and a voice which would obey it in the most perfect manner; for he sung, and performed on the flute, with great taste and feeling. . . . Without having studied drawing, he had acquired a considerable power of expression with his pencil, both in figures and in landscape. . . . Figure, indeed, of every kind, attracted his attention. . . . Even a retort, or a crucible, was to his eye an example of beauty or deformity. . . . These are not indifferent things; they are features of an elegant mind, and they account for some part of that satisfaction and pleasure which persons of all different habits and pursuits felt in Dr. Black's company and conversation.

". . . I may almost say that the love of propriety was the leading sentiment of Dr. Black's mind. This was the first standard to which he appealed in all his judgments; and I believe he endeavoured to make it the directing principle of his conduct. . . .

"Dr. Black had the strongest claim to the appellation of a man of propriety and correctness. His friend Dr.

Ferguson [ADAM FERGUSON, Professor of Mathematics in the University, and a near relation of BLACK's] knew him well, and can delineate his moral features infinitely better than I can. Dr. Ferguson says of him,—

"'As Dr. Black had never any thing for ostentation, he was, at all times precisely what the occasion required, and no more. Much as he was engaged in the details of his public station, and chemical exhibitions, his chambers were never seen lumbered with books and papers, or specimens of mineralogy, &c., or the apparatus of experiments. Nor did any see Dr. Black hurried at one time to recover matter which had been improperly neglected on a former occasion. Every thing being done in its proper season and place, he ever seemed to have leisure in store; and he was ready to receive his friend or acquaintance, and to take his part with cheerfulness in any conversation that occurred. And, let me remark, that no one ever with more ease to himself refrained from professional discussions of any sort, or conversation in which he was acknowledged superior,—or with less self-denial, in mixed company, left the subject of conversation to be chosen by others.'"

The three caricatures of BLACK here reproduced were made in 1787 by JOHN KAY (1742–1826), a Scottish etcher, entirely self-taught, who from 1785 until his death etched nearly 900 plates of the oddities and celebrities of Edinburgh. Almost every notable Scotsman of the period was included. KAY's work thus affords a quaint picture of the social life and popular habits of Edinburgh at its most interesting period. It was collected by HUGH PATON and published in two volumes under the title *A Series of Original Portraits and Caricature Etchings by the Late John Kay, with Biographical Sketches and Illustrative Anecdotes* (Edinburgh, 1837 and 1838). The biography of BLACK and the anecdotes of his relations with JAMES HUTTON, the geologist, which these volumes contain, are also of interest.

Lecturing. [Caricature by John Kay.]

Good caricatures, like good portraits, are always of value to the student of the history of science. They may depict facts in the life of the

Conversing with James Hutton. [Caricature by John Kay.]

person caricatured or may exaggerate personal traits or habits in a way that a true portrait cannot do. Thus from the friendly caricature of BLACK "Lecturing," which is here reproduced, one would conclude that he was a deliberate and complacent lecturer, quiet in manner, and precise in speech, who performed experiments with neatness and success. These characteristics are embodied in the two portraits, but in the portraits they are not humorously accentuated by the wig, glasses and gown as they are in the caricature. That they are not unduly exaggerated is attested by ROBISON who writes that BLACK lectured for thirty years, to audiences which increased from year to year,

"... endeavouring every year to make his courses more plain and familiar, and illustrating them by a greater variety of examples in the way of experiment. No man could perform these more neatly and successfully. They were always ingeniously and judiciously contrived, clearly establishing the point of view, and never more than sufficed for this purpose. While he scorned the quackery of a

Walking. [Caricature by John Kay.]

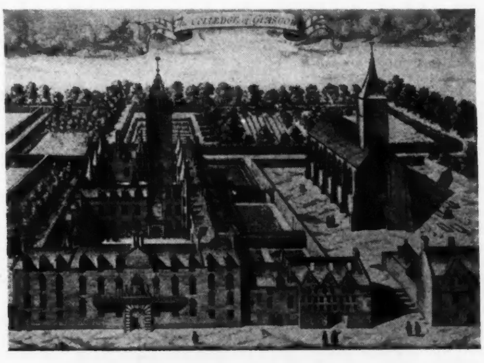
showman, the simplicity, neatness and elegance with which they were performed, were truly admirable. Indeed, the *simplex munditiis* stamped everything he did. I think that it was the unperceived operation of this impression that made Dr. Black's lectures such a treat to all his scholars. They were not only instructed, but (they knew not how) delighted; and without any effort to please, but solely by the natural emanation of a gentle and elegant mind, . . . Dr. Black became a favourite lecturer; and many were induced, by the reports of his students, to attend his courses, without having any particular relish for chemical knowledge, but merely in order to be pleased. This, however, contributed greatly to the extending the knowledge of chemistry; and it became a fashionable part of the accomplishment of a gentleman.

". . . His [BLACK'S] voice in lecturing was low, but fine; and his articulation so distinct that he was perfectly well heard by an audience consisting of several hundreds. His discourse was so plain and perspicuous, his illustration by experiment so apposite, that his sentiments on any subject never could be mistaken, even by the most illiterate; and his instructions were so clear of all hypothesis or conjecture, that the hearer rested on his conclusions with a confidence scarcely exceeded in matters of his own experience."

A description of BLACK'S lectures and their effect upon his hearers, so vivid and enthusiastic that it is worth reproducing in its entirety, is given in the posthumous autobiography[1] of HENRY LORD BROUGHAM (1778–1868), who upon entering the University of Edinburgh in 1792 devoted himself at first to the study of natural science and mathematics but later turned to law and politics and became Lord Chancellor of England. BROUGHAM writes as follows:

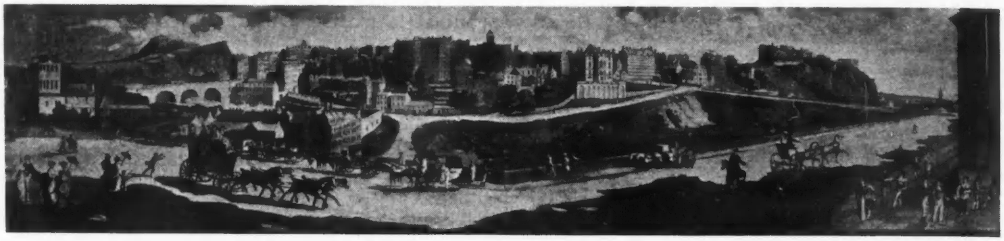
"Great as was the pleasure and solid advantage of studying under such men as Playfair and Stewart, the gratification of attending one of Black's last courses exceeded all I have ever enjoyed. In my life of that great man ('Lives of the Philosophers') I have attempted to describe that pleasure. Not a little of this extreme interest certainly belonged to the accident that he had so long survived the period of his success—that we knew there sat in our presence the man now in old age reposing under the laurels won in his early youth. But, take it altogether, the effect was such as cannot well be conceived. I have heard the greatest understandings of the age giving forth their efforts in their most eloquent tongues—have heard the commanding periods of Pitt's majestic oratory—the vehemence of Fox's burning declamation—have followed the close-compacted chain of Grant's pure reasoning—been carried away by the mingled fancy, epigram, and argumentation of Plunket; but I would without hesitation prefer, for mere intellectual gratification (though aware how much of it is derived from association), to be once more allowed the privilege which I in those days enjoyed, of being present, while the first philosopher of his age was the historian of his own discoveries, and be an eyewitness of those experiments by which he had formerly made them, once more performed with his own hands.

"His style of lecturing was as nearly perfect as can well be conceived; for it had all the simplicity which is so entirely suited to scientific discourse, while it partook largely of the elegance of all he said or did. The publica-



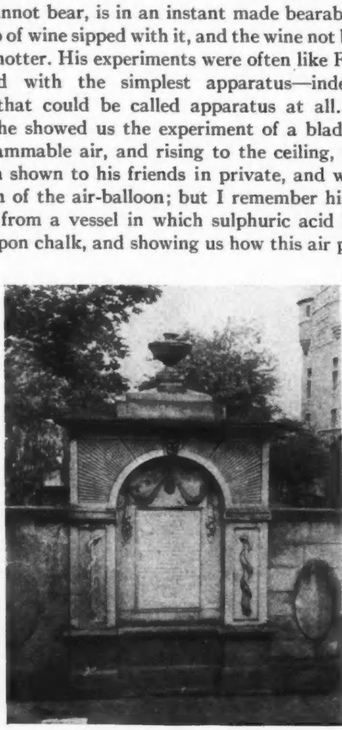
Bird's eye view of the old college of Glasgow at the close of the seventeenth century. [From the engraving in Capt. John Slezer's *Theatrum Scotiae*, 1693.]

[1] (Edinburgh and London, 1871), Vol. 1, pp. 71–76.



View of Edinburgh in the time of Black. [From a color print by A. Kay and I. Clark, published in 1814 by Dan'l McIntosh, Edinburgh.]

tion of his lectures has conveyed an accurate idea of the purely analytical order in which he deemed it best to handle the subject with a view to instruction, considering this as most likely to draw and to fix the learner's attention, to impress his memory, and to show him both the connection of the theory with the facts, and the steps by which the principles were originally ascertained. He would illustrate his doctrine of latent heat by referring to what is seen and felt, but passed without remark, in the boiling of a kettle, and the steam coming from its spout of different heat at different distances; or would remind us of the surprise expressed by finding that boiling water is cooled far more quickly than could be foreseen upon the addition of a very little cold; or that a hot chestnut which the mouth cannot bear, is in an instant made bearable by the least drop of wine sipped with it, and the wine not becoming sensibly hotter. His experiments were often like Franklin's performed with the simplest apparatus—indeed with nothing that could be called apparatus at all. I forget whether he showed us the experiment of a bladder filled with inflammable air, and rising to the ceiling, which he had often shown to his friends in private, and which was the origin of the air-balloon; but I remember his pouring fixed air from a vessel in which sulphuric acid had been poured upon chalk, and showing us how this air poured on a candle extinguished the light.He never failed to remark on the great use of simple experiments within every one's reach; and liked to dwell on the manner in which discoveries are made, and the practical effect resulting from them in changing the condition of men and things.



Black's tomb in Greyfriars Churchyard, Edinburgh.

"The scheme of the lectures may thus be apprehended—the execution imperfectly; for the diction was evidently, in many instances, extemporaneous, the notes before the teacher furnishing him with little more than the substance, especially of those portions which were connected with experiments. But still less can the reader rise from the perusal to any conception of the manner. Nothing could be more suited to the occasion; it was perfect philosophical calmness; there was no effort, but it was an easy and a graceful conversation. The voice was low, but perfectly distinct and audible through the whole of a large hall crowded in every part with mutely attentive listeners; it was never at all forced, any more than were the motions of the hands, but it was anything rather than monotonous. Perfect elegance as well as repose was the phrase by which every hearer and spectator naturally, as if by common consent, described the whole delivery. The accidental circumstance of the great teacher's aspect, I hope I may be pardoned for stopping to note, while endeavouring to convey the idea of a philosophic discoverer. His features were singularly graceful, full of intelligence, but calm, as suited his manner and his speech. His high forehead and sharp temples were slightly covered, when I knew him, with hair of a snow-white hue, and his mouth gave a kindly as well as a most intelligent expression to his whole features. In one department of his lectures he exceeded any I have ever known—the neatness and unvarying success with which all the manipulations of his experiments were performed. His correct eye and steady hand contributed to the one: his admirable precautions, foreseeing and providing for every emergency, secured the other. I have seen him pour boiling water or boiling acid from a vessel that had no spout, into a tube, holding it at such a distance as made the stream's diameter small, and so vertical that not a drop was spilt. While he poured he would mention this adaptation of the height to the diameter as a necessary condition of success. I have seen him mix two substances in a receiver into which a gas, as chlorine, had been introduced, the effect of the combination being perhaps to produce a compound inflammable in its nascent state, and the mixture being effected by drawing some string or wire working through the receiver's sides in an

air-tight socket. The long table on which the different processes had been carried on was as clean at the end of the lecture as it has been before the apparatus was planted upon it. Not a drop of liquid, not a grain of dust remained.

"The reader who has known the pleasures of science will forgive me if, at the distance of much more than half a century, I love to linger over these recollections, and to dwell on the delight which I well remember thrilled me as we heard this illustrious sage detail, after the manner I have feebly attempted to portray, the steps by which he made his discoveries, illustrating them with anecdotes sometimes recalled to his mind by the passages of the moment, and giving their demonstration by performing before us the many experiments which had revealed to him first the most important secrets of nature. Next to the delight of having actually stood by him when his victory was gained, we found the exquisite gratification of hearing him simply, most gracefully, in the most calm spirit of philosophy, with the most perfect modesty, recount his difficulties, and how they were overcome; open to us the steps by which he had successfully advanced from one part to another of his brilliant course; go over the same ground, as it were, in our presence which he had for the first time trod so many years before; hold up, perhaps, the very instruments he had then used, and act over again the same part before our eyes which had laid the deep and broad foundations of his imperishable renown. Not a little of this extreme interest certainly belonged to the accident that he had so long survived the period of his success—that we knew there sat in our presence the man now in his old age reposing under the laurels won in his early youth. But, take it altogether, the effect was such as cannot well be conceived."

From the caricature of Dr. Black "Walking," one would conclude that his constitution was not robust, and that he was moderate and careful in taking exercise; and indeed Adam Ferguson says,

"He guarded against illness, by restricting himself to a moderate, or I should rather call it, an abstemious diet; and he met his increasing infirmities with a proportional increase of attention and care,—regulating his food and exercise by the measure of his strength. It is wonderful with what skill and success he thus made the most of a feeble constitution, by thus preventing the access of disease from abroad. He enjoyed a health which was feeble indeed, but scarcely interrupted, and a mind ever undisturbed, in the calm and cheerful use of all his faculties."

Caricature of the laying of the foundation stone of the new University of Edinburgh, November 16, 1789. [From a print by D. Allan, published by Hugh Paton.]

The third caricature represents BLACK in conversation with his most intimate friend, JAMES HUTTON (1726–1797), Scottish geologist, who in his *Theory of the Earth* laid the foundation of the modern science of geology. ROBISON says of them,

"'He [HUTTON] made up in physical speculation all that was wanting in any of the rest of his [BLACK'S] acquaintance. Yet would it be difficult to say whether the characters of Dr. Black and Dr. Hutton, so often seen together, were most to be remarked for resemblance or contrast. Both profound in physical science; both rigid adherents to fact, in exclusion of all hypothesis, or the most specious conjecture: Both of consummate humanity and candour. Dr. Black was serious, but not morose. Dr. Hutton playful, without petulance. The one was always on solid ground; and of him it might be said, *nil molitur inepte*. The other, whether for pleasantry, or serious reflection, could be in the air, speculate beyond the laws of nature, or their phenomena, and treat the common notion of body, extended and impenetrable, as a vulgar error.' But, with all this diversity of relish, the friends were united by mutual respect for the talents of each other, and the most implicit confidence in each other's integrity and worth. Dr. Hutton was the only person now near him, to whom Dr. Black imparted every speculation in chemical science, and who knew all his literary labours. Seldom were the friends asunder for two days together."

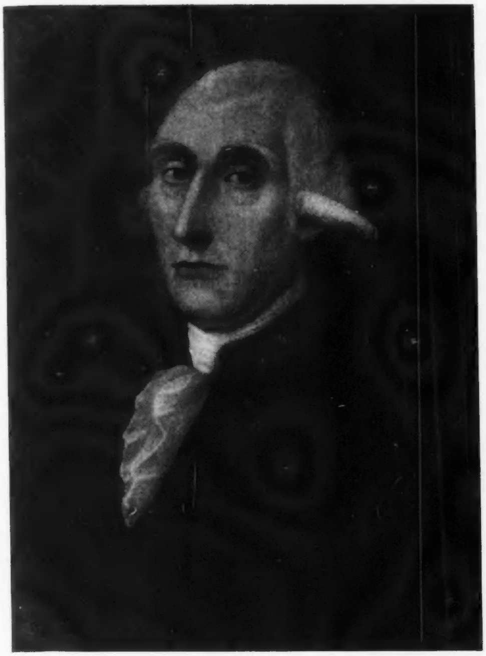
Portrait by Sir Henry Raeburn. [From an engraving by Jas. Heath, published in 1800 by J. Heath and J. P. Thompson.]

BLACK studied and taught at two universities —Glasgow and Edinburgh—but his most important researches were carried out at Glasgow. Both universities have been entirely rebuilt since BLACK'S time, and while a number of views of the old Glasgow university buildings have been preserved (such as the one here reproduced), there are apparently no satisfactory ones of the old Edinburgh buildings. However, although the new University of Edinburgh was not completed during BLACK'S lifetime, it was erected on the site of the old university and so the caricature, here reproduced, of the laying of the foundation stone of the new university gives a good impression of the surroundings of the old as BLACK knew them. The general view of Edinburgh, which is also reproduced, shows Princes Street in the foreground with the old city in the background. The street that crosses the bridge at the left-hand end of the print is the street shown in the caricature. In the caricature the location of the bridge is marked only by the absence of buildings at the end of the street.

BLACK is buried in Edinburgh in the corner of the Greyfriars Churchyard, which in 1679 served as the covenanters' prison. A translation of the inscription on his tomb reads as follows:

Joseph Black, M.D.—born in France, but a British subject, his father being a native of Ireland, and his mother of Scotland—first a student in Glasgow University, then of Edinburgh, in both universities he was a distinguished Professor of Chemistry; a felicitous interpreter of nature, acute, cautious, and skillful in research; eloquent in description; the first discoverer of fixed air [carbon dioxide] and latent heat,—died in the 71st year of his age, A.D. 1799. His friends, who were wont to esteem his work and ability, have sought to mark out the spot which contains his body by this marble as long as it shall last.

It is interesting to note that the original marble tombstone became so decayed that in 1894 the Town Council replaced the marble by a sandstone tombstone. The decay of the marble was, of course, due to the action of the gas, whose presence in the atmosphere BLACK was the first to detect.



Portrait by an unknown Scottish artist. [From a crayon drawing in the Scottish National Portrait Gallery, Edinburgh.]

In view of the present-day tendency to charge BLACK with having fathered the caloric theory of heat, when actually no man of science was ever more cautious in framing hypotheses—indeed "he had an almost morbid horror of hasty generalization or of anything that had the pretensions of a full fledged theory"—it may be worth while to quote the two following passages from ROBISON's biographical preface.

"My acquaintance with him [BLACK] began at Glasgow in 1758, I being then a student in that University; and it began in a way which marked the distinguished amiableness of his disposition and behaviour. It was at the house of one of the Professors, to whom I was telling the great entertainment I had received from the lectures of Dr. Robert Dick, Professor of Natural Philosophy, and how much I admired him as a lecturer. Dr. Black joined in the commendation, and then, addressing himself to me, questioned me a good deal about Natural Philosophy, so as to perceive what were the peculiar objects of my attention. His advices relative to my favorite study were so impressive, and given in a manner so unaffectedly serious and kind, that they are still as fresh in my mind as if of yesterday's date. I was a stranger to him, and not even his pupil; and he was prompted to take that pains with me, solely by the way in which he heard me speaking of the lectures of one whom he loved and esteemed. Gently and gracefully checking my disposition to form theories, he warned me to suspect all theories whatever, pressed on me the necessity of improving in mathematical knowledge, and gave me Newton's Optics to read, advising me to make that book the model of all of my studies, and to reject, even without examination, every hypothetical explanation, as a mere waste of time and ingenuity.···

"Such a man was of the highest value to a celebrated seminary of learning. Ingenious men, of a fertile and lively imagination, are but too apt to give a loose to their fancy, in forming wide-grasping theories, and dressing them out in specious attire. The young student, ardent and credulous, is dazzled by what appears a strong and wide spreading light, not remarking that perhaps it is not the natural emanation from a luminary, but is artificially collected by mirrors and glasses; or that what he takes for real objects are only the shadowy representations by a magic lanthorn. To this, in a great measure, may be ascribed the continual flux of theory which may be observed in all universities. Yet the consequences to science are most unfortunate. Not only do the precious years of youth and of mental energy pass on without solid instruction, but also the most unfortunate of all habits is acquired, that of considering the extensive and plausible application of a theory to the explanation of phenomena as a valid proof of its truth. But, on the other hand, the lectures of such a teacher as Dr. Black, never permitting this play of fancy, and even rarely introducing conjecture, would be safe lessons for ingenuous youth. The affirmations of the professor may be trusted as matter of experience, and the student will acquire betimes the habit of never proceeding in research of any kind, without founding the channel as he advances."

University of Iowa Colloquium on Physics and Society

Devoted to the general subject, "Physics and Society," a colloquium for physicists to be held at the University of Iowa on June 15, 16 and 17, 1939 will include addresses and round-table discussions on a variety of interesting topics such as recent progress in theoretical and experimental physics, the use of mathematics in physics, characteristics and merits of general physics textbooks, x-rays and their applications in medicine and in biological research, and the significance of modern science and technology in current affairs, in man's philosophy and in his physical well-being. Among the other features of the program are demonstration experiments, motion pictures, luncheon and dinner meetings, and the unveiling of a new mural, entitled "Man's Opportunities for a Better Civilization," in the Iowa Physics Laboratory.

The Physics Wing of the New Science Building at Brooklyn College*

Frances Orr Severinghaus
Department of Physics, Brooklyn College, Brooklyn, New York

The citizens of New York City long ago decided that to give their young people a free college education was a worthy investment, and in 1848 City College for men was founded. In 1870 a normal college for women was opened, which later became Hunter College. Students came from all the boroughs of the city, even though for some the commuting time amounted to several hours a day. In 1926 City College established a branch in Brooklyn to care for some of these commuters, and a year later Hunter College organized a Brooklyn unit. Only the first two years of college work were given in these branches. The enrolment increased so rapidly that, with these branches to form the nucleus, Brooklyn College was established in 1930 as a coeducational, four-year college. City College, Hunter, Brooklyn, and the more recent Queens College are all administered under a Board of Higher Education, although they function as separate units.

The classrooms and laboratories of Brooklyn College were established in an old theater and later in several office buildings, some of them five and six blocks apart. The students had to contend with street traffic and with the heavy elevator traffic in these busy office buildings. The noise and dirt and the jarring of the buildings by streetcars and trucks made the science groups extremely uncomfortable. The enrolment continued to increase, however. When the announcement came that the city had purchased a large tract of land out in the Flatbush section and intended to erect new buildings for Brooklyn College, it was received with great enthusiasm.

There are now five fireproof buildings set in 34 acres of land, thus giving room for expansion when the need arises. The buildings are of red, hand-molded brick, with limestone trimmings and slate roofs. They are Georgian in character and are connected by wide cement walks. The library building with its stately white tower forms the center of the group, with the academic building on one side and the science building on the other. There are also a gymnasium building and a heating plant. The buildings are low; the wings have only four floors above ground with an added two stories in the center part. This makes it possible for the students to reach their classes without having to wait for elevators. However, each of the two main buildings has one manually operated elevator and two automatic elevators for which the staff members have keys.

The science building, the mirror image of the academic building, is built in the shape of an *E*. It is 435 ft in length, and the long end-wings are 65×185 ft. It is so long that, to allow for thermal expansion, it has been built in two sections, each with its own foundation piers. The science building accommodates the physics, chemistry, biology, geology and psychology departments. The whole of one of the long wings of the building, with the addition of 2 large lecture rooms on the main corridor, is devoted to physics.

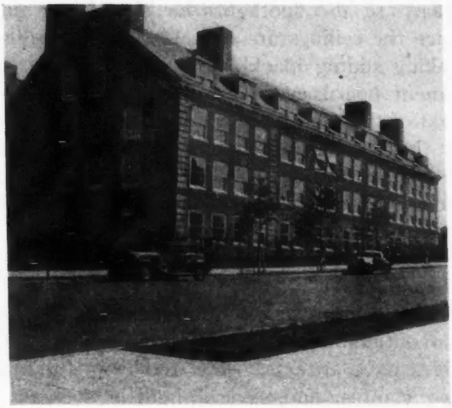
The corridors are 10 ft wide, have floors of cement, and walls of a pleasing shade of green-gray tile reaching shoulder high. Eight wide stairways eliminate congestion and give the students easy access to the classrooms. The radiators and the three refrigerator drinking fountains on each floor are set into the walls so that they take up no floor space.

It has always been the policy of the college to keep the classes as small as possible, the size depending on the subject matter to be presented and the cost of floor space, materials and instruction. In the physics department it has been found that, in an elementary laboratory with no more than two experiments running at a time,

* This article is one of a series on the buildings, equipment and facilities of various physics departments. The articles are also designed to be of help to departments that are planning to build a new laboratory or to remodel and re-equip an old one. Articles previously published are: G. R. Harrison, "Spectroscopy at the Massachusetts Institute of Technology," **1**, 109 (1933); S. L. Brown, "New Physics Laboratory at the University of Texas," **2**, 70 (1934); C. F. Hagenow, "The New Physics Building at Washington University," **3**, 25 (1935); L. M. Alexander, "The Physics Laboratory at the University of Cincinnati," **3**, 123 (1935); L. S. McDowell, "Physics at Wellesley," **4**, 57 (1936).—The Editor.

one instructor can take care of as many as 20 students in a section. Recitation sections are also limited to 20 students, although the lectures are given to three or four such groups at a time. This arrangement determined the size of the lecture rooms and laboratories. There are 2 lecture rooms, each seating 80 students, 6 laboratories, and 15 recitation rooms for the work of the first and second semesters of general physics. These two semesters are given in parallel. Some 15 to 20 intermediate and advanced courses make use of 6 small lecture rooms and 6 laboratories. The small offices and research rooms are bays, 10×25 ft. The lecture rooms, recitation rooms and laboratories are multiples of these dimensions. On each floor these rooms have been so grouped that, when the need for more student laboratories arises, two adjacent recitation rooms and a research room can be turned into a laboratory and its accompanying apparatus room with very little expense.

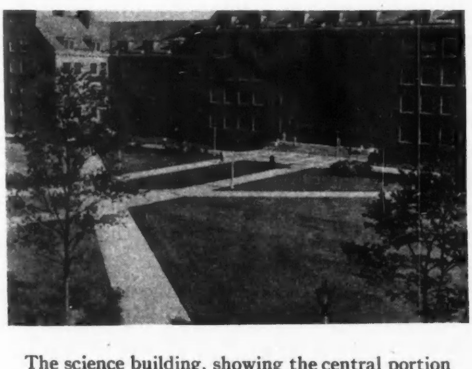
All rooms are equipped with Austral windows, counterbalanced so that the upper and lower sashes balance each other; they are excellent for ventilation purposes and are provided with shades for each half, which makes it possible to darken the room and have fresh air at the same time. Semi-indirect lighting fixtures with closed globes give from 8 to 14 foot candles of illumination at the working surface. All rooms have thimbles, or small holes, a foot or more below the ceiling and also through the floor so that additional electric wiring can be carried from one room or floor to another without going into the corridors. Each laboratory and research



The physics wing.

room is equipped with gas, water, compressed air, a.c. and d.c. wall outlets, and a switchboard for various services. Wall strips for mounting apparatus are provided. The sinks have special acid-resisting traps and drains. An examination of the water showed that in this locality brass pipes would be best. All the floors are cement except in the offices, where asphalt tile was used, and in the machine and carpenter shops, which have battleship linoleum on the floors.

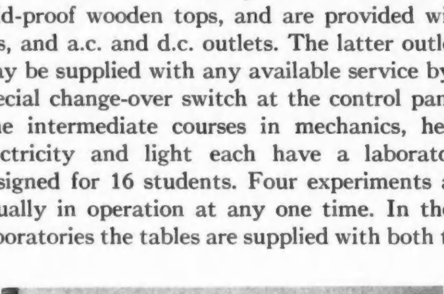
The lecture rooms are equipped with permanently attached chairs, with the rear rows raised above the floor level so that every student has a clear view of the lecture table and blackboard. The ceilings and walls of the larger lecture rooms have received acoustical treatment. Forced ventilation is employed. The lecture tables are in two sections with a 3-ft gap which can be filled by specially designed rolling tables. Lecture demonstrations can be set up on these tables in the apparatus room and then rolled into the gap in the lecture table. The general room lighting consists of two separate circuits which are controlled by momentary contact switches. One circuit gives normal illumination; the other, less than normal or approximately full moonlight, for taking notes while viewing the projection of slides. It is planned to control this lighting by means of a rotating bar running the whole length of the blackboard just below the chalk rail so that the lecturer can change the illumination from any point at which he may be standing.



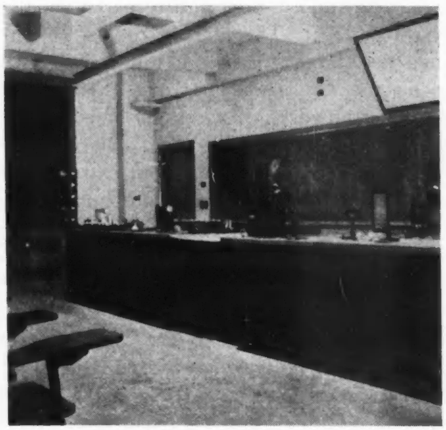
The science building, showing the central portion and one wing.

There are also spotlights for the lecture table. Since the ceilings are only 11 ft from the floor, making sliding blackboards impracticable, permanent boards were installed across the entire front of the room. The space under them is used for the distributing panel for all electric service to the lecture table. The lecture tables are equipped with a.c. and d.c. outlets at the front, back and ends. These are located on the vertical surfaces of the tables so as to keep the tops clear. Five feeders for various services lead to the tables from the distributing panel. There are also outlets for gas and compressed air. The tables have an extra wide overhang, for table-edge clamps, and several built-in sockets for vertical rods. In the elementary mechanics lecture room a Megavac pump is permanently installed in the table. In lecture rooms where electric equipment is used, several rheostats are installed in the lecture tables.

The laboratories are 25×40 ft, or larger. Each has its own apparatus room and a small coat room. All laboratory tables have black, acid-proof wooden tops, and are provided with gas, and a.c. and d.c. outlets. The latter outlets may be supplied with any available service by a special change-over switch at the control panel. The intermediate courses in mechanics, heat, electricity and light each have a laboratory designed for 16 students. Four experiments are usually in operation at any one time. In these laboratories the tables are supplied with both the usual outlets and large 3-pole outlets for special services. In addition, all the a.c. and d.c. outlets may be changed over to special services. The optics laboratory has its own photographic darkroom with a labyrinth entrance so that several students can use the room at one time. The laboratory itself can be made completely dark for projection of diffraction patterns. There is also another photographic darkroom in the physics wing for the general use of the staff. The advanced physical laboratory consists of 8 small rooms, which makes it possible to set up special experiments and leave them for several weeks at a time. Two of these rooms can be completely darkened. These laboratories are provided with special ground wires which lead far below the foundations of the building to a plate in permanently moist ground. Several of these rooms have a sleeve placed a little above table level so that special electric service can be led from the switchboard or apparatus in one room to a table in the adjoining room. For experiments requiring long tubes or free fall, a 3-in. hole from the basement to the fourth floor has been made with sleeves through the floors and deck plates on the floors.

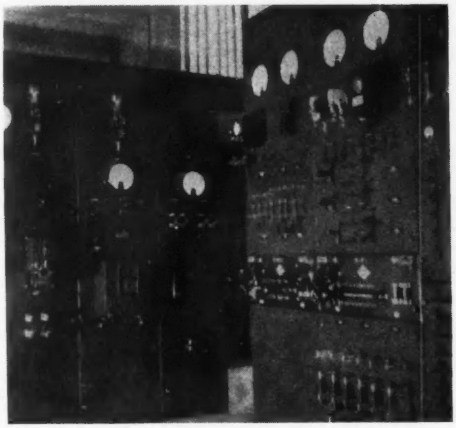


Telescope dome with biology greenhouse in the foreground.



A lecture room.

The courses in astronomy have a small lecture room and a laboratory for calculation and measurements. The observatory and transit room are on the top floor of the center wing. The dome



Generator and general service switch boards.

of the observatory, built by Warner and Swasey, is 17 ft in diameter. The telescope is a 7-in. refractor designed and constructed by J. W. Fecker. It is mounted on I-beams that go directly into the walls of the observatory room, and the floor is suspended by I-beams not in contact with the I-beams that support the telescope.

The stock room, a large storeroom, and machine and carpenter shops are on the first floor, convenient to one of the entrances. There are also 9 small storerooms, two or more on a floor, conveniently arranged for storing supplies and making use of floor space unsuitable for other purposes.

At present the college buys a.c. power but generates all the d.c. and special services required. The main d.c. motor-generator set supplies the entire science building; it consists of two 120-v, 40-kw generators driven by a common motor. The distribution is a 3-wire system with the central wire grounded, thus making 240-v available. A line from the generator goes directly to the physics department, so that line drops due to heavy loads drawn by other departments are avoided. For the same reason, the physics department has a separate line, independent of the lighting distribution, from the main transformer supplying the science building.

Distribution of a.c., d.c. and special services to all physics department rooms originates in a single room in the basement of the physics wing. This room contains the various motor-generator sets and is adjacent to the battery room. The following special services are available: (1) 120-v d.c. from a 12-kw generator; this is used for general work when the main d.c. generator is turned off, for battery charging, and for emergencies; (2) 120-v storage battery of 240 amp hr capacity at 30-hr rate; by special switching arrangements the quarter-sections or half-sections may be placed in parallel to get 30 or 60 v; (3) 24-v battery of 400 amp hr capacity at 30-hr rate; this is tapped at points 18, 12 and 6 v; (4) 30-v d.c. generator for battery charging; (5) 4- or 8-v d.c. from a generator for general low-voltage laboratory work; (6) 20-v, 960-cycle a.c. from a 1-kva generator driven by a synchronous motor; (7) 208-v, 3-phase, 60-cycle power which is purchased. The field excitation for the 1000-cycle and 4- to 8-v generators can be supplied either from the 120-v line or from the 120-v battery. The remaining generators are self-excited. The battery-charging panel is equipped with an ampere-hour meter having an automatic cutoff. Provision is made for charging sections of the battery while other sections are in use. All these services are carried to a large panel board from which they are distributed by means of plug jacks to groups of 5 wires leading to the special service panels in the individual rooms. Each group of 5 wires is completely independent of all the rest, and contains two wires rated at 100 amp and three at 50 amp. The line resistance of the larger pair to the most remote laboratory is less than 0.1 ohm.

Careful planning has made the physics wing of the science building not only efficient in its arrangement and equipment but exceedingly comfortable for both students and staff.

Part-Time Instrument Maker and Mechanician Available

A young man who has worked full time for 7 yrs in the shops of the Central Scientific Co., in every branch of instrument and apparatus making, involving all kinds of machine work, desires a part-time position in the instrument shop of a physics department in order that he may complete his college course. He is 22 yrs old, is a high school graduate and has successfully completed his first semester of college work. Address inquiries to the Editor.

DISCUSSION AND CORRESPONDENCE

The Theoretical Treatment of Hooke's Law

I HAVE checked through a considerable number of elementary textbooks of college physics and have not found any theoretical consideration of Hooke's law. A simple treatment that might be useful to teachers of elementary physics is as follows:

Let us designate by x the mean distance between the molecules of a substance. Furthermore, let us assume that both attractive and repulsive forces between the molecules are functions of x; then the net force is some function of x, let us say $f(x)$. Using the Taylor series, we get

$$f(x)-f(x_0)=f'(x_0)(x-x_0)+\cdots,$$

where $f'(x_0)$ is the first derivative of $f(x)$, evaluated at x_0.

Now if $f'(x_0)\neq 0$ and $x-x_0$ is small compared to x, we see that $f(x)-f(x_0)$ represents the restoring force, $f'(x_0)$ is a constant, and $x-x_0$ is the displacement. Therefore the restoring force is proportional to the displacement. The discussion can be extended for a body of many molecules.

A more complete discussion of the relation between the displacement and the restoring force may be found in *Theoretical Physics* by G. Joos,[1] or *Introduction to Theoretical Physics* by J. C. Slater and N. H. Frank.[2]

ZIGMOND WILCHINSKY

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[1] G. Joos, *Theoretical Physics*, translated from first edition by I. M. Freeman (Stechert, New York, 1934), Chapter VIII.
[2] J. C. Slater and N. H. Frank, *Introduction to Theoretical Physics* (McGraw-Hill, ed. 1, 1933), Chap. XVI.

The Third Law of Motion

IN SOME expositions of mechanics, equilibrium is explained in terms of Newton's third law of motion. In one book it is stated:

> Thus if a barrel of flour is suspended by a rope (and is at rest), the attraction of gravity—the pull of the earth—will be represented by a vector pointing downward and of length W, the weight of the barrel. On the other hand, the force which the rope exerts on the barrel will be represented by an equal and opposite vector pointing upward. For action and reaction are equal and opposite.

In this example the weight and the force exerted by the rope, which act on the body and balance each other, are assumed to be related as action and reaction. In another book, problems in equilibrium are analyzed and then the author says, "The illustrations of balanced forces in Articles 24 and 33 are examples of Newton's third law." Equilibrium is again treated in terms of the third law. In the present note it is argued that principles of equilibrium do not exemplify the third law.

For purposes of exposition, let us consider a block that rests upon a table. Considering only vertical forces, identify the actions and reactions. One force acting on the block is the weight of the block $-W$, which is exerted by the earth. The reacting force is the attraction of the block for the earth. The block presses on the table and the table reacts on the block with an upward force P of equal magnitude. The equilibrium of the block is expressed by the equation $P-W=0$, or $P=W$, but $-W$ and P are not related as action and reaction. These balanced forces act on the block, whereas action and reaction act on different bodies.

In order to strengthen the argument that $-W$ and P are not related as action and reaction, let us consider the situation when the table is accelerated upward. The magnitude of P is then greater than that of $-W$; and, if P and $-W$ were action and reaction, the third law would not hold during acceleration, which is contrary to the assumption that it is a universal law. The proponent of the third law may reply, however, that when the block is accelerated there is a kinetic reaction $-ma$ so that $P-W-ma=0$, or $P=W+ma$. In order to explain the role of this kinetic reaction it is necessary to go back to first principles.

According to Newton's second law, the acceleration of a body is determined by the sum of the forces acting on the body in accordance with the equation $F=ma$. A special case of motion is equilibrium for which the condition is $F=0$. It is to be emphasized that equilibrium is determined by forces acting *on* a body. Now a problem in acceleration may be expressed mathematically as a problem in equilibrium by transforming $F=ma$ into $F-ma=0$ and calling $-ma$ an *inertial resistance*. This inertial resistance is to be viewed as acting on the given body, so that F and $-ma$ are treated as balanced forces acting on the same body.

In the preceding paragraph no use was made of the third law. A typical phenomenon which exemplifies the third law is the collision of two billiard balls A and B. During the interaction A exerts a force on B, and B exerts a force equal in magnitude and opposite in direction on A. In this simple example action and reaction act on different bodies. The reaction to the force exerted by A on B is a resistance exerted by B on A, but is not a force on B. The analysis of the forces in the problem of the block on the table also showed that action and reaction act on different bodies. These illustrations of the third law hold whether an accelerated motion is treated as a problem in acceleration or in equilibrium. The reaction to a force may be exhibited without introducing the concept of kinetic reaction.

If $F-ma=0$ is interpreted with the aid of a kinetic reaction $-ma$, the so-called kinetic reaction is not to be interpreted as the reaction to F, but as a resistance similar

to friction which acts on the body as does F. The third law prompts us to find a reaction for this inertial resistance, and our inability to exhibit it indicates that inertial resistance is introduced only to transform a mathematical problem of acceleration into one of equilibrium.

The third law applies to forces that act on different bodies; the principles of equilibrium apply to forces that act on the same body. Hence a principle of equilibrium should not be offered as an exemplification of the third law. Likewise a problem of acceleration which has been transformed into one of equilibrium by the introduction of an inertial force is not described by the third law. Indeed, it is logically possible for the principles of equilibrium to be true and the third law to be false.

V. F. Lenzen

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Berkeley, California.

Charles-Édouard Guillaume, 1861–1938

NEWS has reached America to the effect that M. C.-E. Guillaume departed this life at the advanced age of 77. Monsieur Guillaume served as director of the International Bureau of Weights and Measures at Sèvres for 53 years, and it may be unqualifiedly said that he held this post with efficiency and honor. The Bureau, as its name implies, is truly *international* in its organization and scope, being maintained jointly by some 32 governments; and among these the leading nations of the globe are represented.

Charles-Édouard Guillaume was born at Fleurier, Switzerland, on February 15, 1861. He was educated at Neuchâtel; and, having become a *docteur-ès-sciences*, he made the study of practical physics his life work.

Guillaume is perhaps best known for his invention of the alloy called *invar*, which is composed of iron, nickel (36 percent), and carbon (0.2 percent). This metal, which is in reality a kind of steel, possesses the peculiar property of expanding and contracting only very slightly with changes of temperature; hence it has been much used for high precision rules and tapes, and other instruments.

Apart from his work on the nickel-iron alloys, for which he was awarded the Nobel prize in 1920, Guillaume made valuable contributions to the following subjects: the precise determination of temperature, novel radiations, x-rays, the volume of the kilogram of water, compensation of clocks and watches, and the metric system in general. Moreover, he went far toward erecting his own memorial in writing *La création du Bureau International des Poids et Mesures et son œuvre*.

It is obvious from the foregoing statements that Guillaume occupied himself, for the most part, with the exact determination of quantities. To many persons, doubtless, such work may appear both prosaic and uninteresting. Yet its vast importance in human affairs has long been realized. For instance, the Greek philosopher Plato, who lived more than two thousand years ago, wrote thus regarding it: "If from any art you take away that which concerns weighing, measuring, and arithmetic, how little is left of that art!" In different phraseology, the value of science must depend primarily upon the reliability of its data, and through careful measurement alone are such data to be obtained.

William M. Thornton, Jr.

Loyola College,
Baltimore, Maryland.

Appointment Service

REPRESENTATIVES of departments or of institutions having vacancies are urged to write to the Editor, Columbia University, for additional information concerning the physicists whose announcements appear here or in previous issues. *The existence of a vacancy will not be divulged to anyone without the permission of the institution concerned.*

25. Ph.D. Yale. Age 33, married, 2 children. Industrial research experience; 3 yrs instructor in small college. Interested in teaching in coeducational or mens liberal arts college. Available June 1938.

26. Ph.D., with long experience in an American college in China, wishes a college teaching position.

27. Ph.D., physics, Northwestern '35; A.B., engineering, Harvard. Age 42, married, 3 children. Experience: 1 yr, lt., artillery; 12 yrs business and sales; 5 yrs college teaching. Interested in undergraduate teaching, including astronomy.

28. B.S. in E.E., M.S., physics, Dr. Phil. Nat. from German univ. (Exchange fellow from U. S.) Age 33. 7 yrs teaching experience in advanced courses and physics for engineers.

29. Ph.D., Northwestern; M.S., Pittsburgh; A.B., Muskingum. Age 34, married, 1 child. Has had 13 yrs teaching experience in two universities. Interested in teaching and research.

30. Ph.D., Univ. of Chicago. Many years experience as head of department of physics in prominent college. Author of books on physics and history of science. Large work on history of physics in preparation. Interested in college or university teaching.

31. Ph.D. Columbia. Years of experience as head of departments of physics in colleges and universities. Author of new type of laboratory manual. Designer of many new types of simplified apparatus. Research in radio, acoustics and methods of teaching physics.

32. Ph.D., Age 33, married. Experience: 4 yrs secondary school; 4 yrs instructor state university; 3 mo industrial research; 4 yrs head of physics and mathematics departments in liberal arts college, where now employed. Author of laboratory manual. Three research grants. Desires position in larger college or university.

33. M.S., experimental physics, coupled with thorough background of courses in professional education. Has taught physics and mathematics for 3 yrs in large high school. Desires position as instructor in high school physics in a university or college experimental or training school.

Departments having vacancies or industrial concerns needing the services of a physicist are invited to publish announcements of their wants; there is no charge for this service.

Summer Meeting of the Association at Stanford University

The American Association of Physics Teachers will meet at Stanford University on June 28, 1939. Professor Paul Kirkpatrick of Stanford University is Chairman of the Local Committee in charge of the meeting.

NOTES ON APPARATUS AND DEMONSTRATIONS

Force in an Elevator Cable

IN TEXTBOOKS and in some laboratory manuals, under the heading of the Atwood machine, the force in a cord by means of which a load is being lifted is discussed as a problem in accelerated motion. In order to magnify the change in force and enable students to determine it quantitatively, a special piece of laboratory equipment was devised. The apparatus consists essentially of a hoisting drum (Fig. 1) that has three cylindrical portions, of two

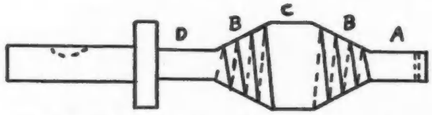

FIG. 1. Special hoisting drum for study of acceleration.

different diameters, separated by two conical portions. The dimensions of the drum must be chosen to suit the space in which it is to be used. For instance, in the laboratory where the apparatus was first tried, a vertical lift of about 2 m was possible and the drum had the following dimensions (Fig. 1): cylinder A, diameter $\frac{1}{4}$ in., length $\frac{3}{8}$ in.; cones B, each of length $\frac{1}{2}$ in., with 4 threads of $\frac{1}{8}$-in. pitch, measured along the axis, cut to extend from the smaller to the larger cylinder; cylinder C, diameter $\frac{3}{4}$ in., length $\frac{3}{8}$ in.; cylinder D, diameter $\frac{1}{4}$ in., length $\frac{1}{2}$ in.

The drum is placed in the spindle of a laboratory rotator. A thread, attached to the outer end of cylinder A, is placed over pulleys arranged so that it can be used to lift a weight from the floor toward the ceiling. The pulley at the ceiling is supported on a spring balance and hence twice the force in either thread may be observed. While the thread winds along cylinder A, the weight rises with constant speed. During this time it is observed that the balance reading is identical with that shown when the weight is suspended without moving. When the thread reaches the small end of cone B, it is caught by the helical thread cut on the drum and is carried from a drum of diameter $\frac{1}{4}$ in. to one of diameter $\frac{3}{4}$ in. while the drum undergoes 4 rotations with constant angular speed. A little consideration will show that during this time the weight rises with constant acceleration. At the same time the reading of the spring balance increases, showing that the force in the thread is increased. While the hoisting thread winds on cylinder C, the weight rises faster than before, but the reading of the balance is again the same as when the weight is held stationary. When the thread winds down the second cone B to cylinder D, the reading of the spring balance decreases. On cylinder D the balance reading regains its constant value. If the motor is now reversed and the weight lowered to the floor, the changes of force take place in reverse order.

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T. H. STEVENS

A Fractional-Volt Cell

IN THE electrical laboratory there is frequent demand for a source of emf of 0.1 v, or even lower order. This is usually obtained with a potential divider, used in conjunction with a dry, gravity or secondary cell. But where equipment is limited, or a large number of measurements are being conducted simultaneously, the use of resistance boxes for potential dividers is inconvenient and uneconomical. For most measurements sliding contact rheostats are unreliable.

A simple device for supplying fractional voltages, with the elimination of potential dividers, has been built and tested. It is essentially a mounting for a "voltaic pile," consisting of a metal yoke, through the center of which passes a screw, and a metal plate beneath the screw (Fig. 1). The screw has a knurled head. Yoke and metal

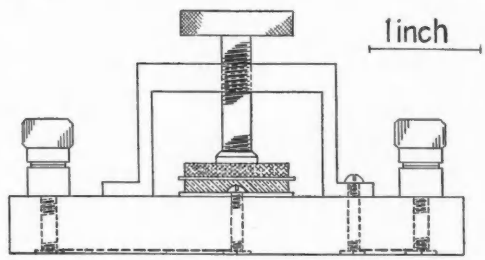

FIG. 1. Diagram of fractional-volt cell.

plate are each connected to binding posts at the edge of the base upon which the device is mounted. A voltaic cell is formed by clamping to the metal plate, by means of the screw, disks of two dissimilar metals (or alloys) between which has been placed a strip of blotting paper soaked with an electrolytic solution. By increasing the number of disks, and using suitable metals, it is apparent that a large variety of voltages may be obtained. Fractional voltages may be obtained by choosing metals whose electrode potentials are near each other, or by choosing a metal and an alloy of that metal.

Potentiometer measurements on this device—using a $0.5N$ acetic acid solution, and various metals of ordinary, commercial quality—have given voltages ranging from 0.012 to 0.109 v. With one electrode of 75 percent copper and 25 percent nickel, and the other of pure copper, an emf of 0.023 v was observed. The cell thus formed was successfully used to calibrate a galvanometer having a figure of merit of 7.5×10^{-10} amp/scale div. Only one resistance box, in series with the meter and cell, was employed. This measurement ordinarily requires two or three resistance boxes.

The cell, without preliminary calibration, may be conveniently used in the many measurements requiring a

small emf whose value need not be known. Satisfactory values for galvanometer resistance have been determined by the half-deflection and the Kelvin bridge methods without the use of the potential dividers otherwise required.

Observations indicate that the cell combinations tested cannot deliver large currents without appreciably impairing the terminal emf. Standing idle, the copper-nickel and copper cell previously mentioned was found to drop about 14 percent in voltage in one hour.

W. JAMES LYONS

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New Orleans, Louisiana.

Electric Wiring and Apparatus Board

THE wiring board shown in Fig. 1 provides one way to introduce practical material into the ever broadening school or college course in general physics without having to take up too much valuable time with trips to basements and power plants. Such boards have long been in use; but often they are not constructed in a practical manner or assembled so as to illustrate code requirements of the Insurance Underwriters. The board shown is slightly smaller than an ordinary portable blackboard. It can be placed on top of a table for demonstration and, when not in use, stored in small space by removing the demountable feet.

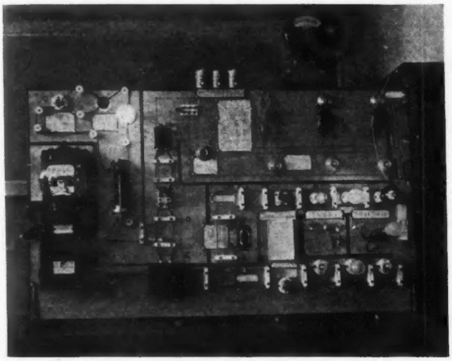

FIG. 1. Wiring and apparatus board.

The following apparatus is mounted on the board: kilowatt-hour meter;[1] service entrance box;[1] cutout box containing a 2-fuse, solid, neutral cutout; armored cable and ends; 52-ohm, 3-amp, slide wire rheostat; double plug-in receptacle; split knobs and porcelain tubes; 2-wire porcelain cleats; 3-way toggle switches and switch bases; double-pole, single-throw switch; double-pole, double-throw switch; single-pole toggle switch and wall box; bell transformer; single-pole snap switch and switch base; cleat receptacles; return call push bottons; single-pole push button; three bells; dry cells; light bulbs, arranged to show their evolutionary development; drop cord receptacle; 1, 30-amp and 2, 10-amp fuses; Nos. 14, 10 and 20 copper wire; wire loom. The large voltmeter-ammeter is separate from the board.

The board may be used to demonstrate the following topics: wiring circuit of a typical house; measurement of electric energy; meter reading; types of wire; current and potential differences in series and parallel circuits; bell circuits, return call and master; 3-way circuits, used in hall and stairway lighting; types of fuses, why they burn out, and how to replace them; function of rheostat; uses of test bulb; types of bulbs; how to use a transformer; a.c. and d.c. bell circuits; code requirements.

Binding posts placed inside the service entrance box, below the meter, make it possible to apply direct current to everything on the board except the meter and transformer. The double-pole, double-throw switch at the top of the board may be used to connect the dry cells to the bell circuits.

The board was built by students. Two N. Y. A. students keep it up-to-date as regards code requirements.

J. T. PETERS

Overbrook High School,
Philadelphia, Pennsylvania.

[1] Loaned by the Philadelphia Electric Co.

An Appeal from China for Scientific Literature

In a recent communication addressed to the American Association of Physics Teachers, T. L. Yuan, Acting Director of the National Library of Peiping, points out that much scientific work is being carried on in China in spite of the war but that the destruction of many universities and scientific institutions has created an urgent need for scientific literature. Because of the military occupation of Peiping, the Library has established an office at Kunming, Yunnan, China, and is attempting to assemble there a special reprint collection. American physicists are requested to send sets of their reprints to the Acting Director. There is also an urgent need for books and periodicals, old or new, especially standard works. Donations of books may be sent in care of the International Exchange Service, Smithsonian Institution, Washington, D. C., which makes monthly shipments to China.

RECENT PUBLICATIONS AND TEACHING AIDS

First-Year Textbooks and Manuals

A Manual of Experiments. Robert Andrews Millikan, Director of the Norman Bridge Laboratory of Physics, California Institute of Technology; Henry Gordon Gale, Professor of Physics, University of Chicago; and Charles William Edwards, Professor of Physics, DukeUniversity. Rev. ed. 227 p., 134 fig., 16 tables, 18×26 cm. *Ginn*, $1.10. This manual is designed to accompany the authors' revised text, *A First Course in Physics for Colleges*. Several of the 55 experiments differ from those in the 1930 edition and new problems have been added in some of the experiments.

Physics—A Textbook for Colleges. Ed. 3. Oscar M. Stewart, Professor of Physics, University of Missouri. 760 p., 500 fig., 3 plates, 15×24 cm. *Ginn*, $4. While the present edition of this well-known text has the same general purposes and scope as the 1924 and 1931 editions, many chapters have been rewritten and some 700 new problems have been provided. The first four chapters have been rearranged so as to deal with liquids, gases, units of measurement and force in the order named. The material on recent developments and modern applications in physics has been brought up to date and expanded. A new chapter on atomic transformations replaces the old chapter on radioactivity. In electricity, frequent reference is made to the mks system of units; this system eventually may replace the cgs system in all fields of physics, but the author believes that for the present it is best to be conservative in our use of it in an elementary text. Five pages of concise "Notes on the Scientific Method" are provided in an appendix.

Intermediate and Advanced Textbooks and References

The Physical Properties of Colloidal Solutions. Ed. 3. E. F. Burton, Director of the McLennan Laboratory, University of Toronto. 243 p., 36 fig., 38 tables. *Longmans*, $5.75. About half the material is new in the present edition of this book for students of physics, industrial chemistry and biochemistry. There are completely new chapters on the forces in liquids that regulate the size of colloidal particles and on the many methods for determining the Avogadro number, the latter chapter being exceptionally complete. Added emphasis has been placed on the treatment of the Brownian movement of colloidal particles. A very complete account of work on sedimentation and the various forms of ultracentrifuge is included. The edition was prepared with the assistance of May Annetts Smith.

A Textbook on Crystal Physics. W. A. Wooster, Lecturer in Mineralogy and Petrology, University of Cambridge. 312 p., 108 fig., 40 tables, 13×21 cm. *Cambridge Univ. Press* and *Macmillan*, $4. Intended primarily for students who are familiar with the elements of crystallography as well as physics, this textbook presents the classical treatment of the physical properties of crystals in terms of tensor notation, and indicates the lines of development of modern theoretical and experimental research in this borderland field between physics, chemistry, metallurgy and crystallography. The chapter headings are: Application of tensor notation to crystal physics; Homogeneous deformation, thermal expansion and plastic deformation; Conduction; Magnetic and electric induction; Some problems in crystal optics; Piezoelectricity; Pyroelectricity; and Elasticity.

Magnetism. 110 p., 47 fig., 3 tables, 15×24 cm. *Institute of Physics* (London), 4s.6d. net, 4s.10d. post free. For many years the Institute of Physics (London) has arranged summer conferences under the auspices of its branches, with the object of bringing together physicists in the industries and in the universities for a series of survey papers on some branch of the science in which progress has been rapid. The present book—one of the resulting series on *Physics in Industry*—contains the principal lectures given at the conference on magnetism held at Manchester in 1937. It contains a foreword by W. L. Bragg and the following lectures: Magnetism and the electron theory of metals, by N. F. Mott; Electrical sheet steel, by G. C. Richer; Influence of the properties of available magnetic materials on engineering design, by C. Dannatt; Magnetization curves of ferromagnetics, by E. C. Stoner; Permanent magnets, by D. A. Oliver; and X-ray studies of permanent magnets of iron, nickel and aluminum, by A. J. Bradley. Each lecture is accompanied by a bibliography.

A College Course in Sound Waves and Acoustics. M. Y. Colby, Professor of Physics, University of Texas. 367 p., 109 fig., 8 tables, 14×22 cm. *Henry Holt*, $2.80. The purpose of this text is to provide a 2- or 3-credit course for students who have had a first course in general physics and who are interested in both the physical principles and industrial applications of wave motion and sound. The first chapter, 40 pages, provides a review of the material usually covered in a first-year course and a preview of the treatment to come. The remaining 11 chapters deal with vibrating motion, transverse and longitudinal waves, longitudinal vibrations of bars, speed of sound, interference, beats, combination tones, directed wave trains, intensity of sound by resonance methods and by nonresonant microphones, hearing, and architectural acoustics. Many worked examples, questions and problems are provided. Calculus is not used. The completion tests, one for each chapter, that occupy some 30 perforated pages near the end of the book might well be replaced, in a future edition, by other, much more useful material.

Introduction to Ferromagnetism. FRANCIS BITTER, Associate Professor of the Physics of Metals, Massachusetts Institute of Technology. 325 p., 147 fig., 17 tables, 15×22 cm. *McGraw-Hill*, $4. The principal aims of this book are to define the problems whose solutions should reveal the fundamental processes of magnetism, to pave the way for a consideration of the subject from the point of view of solid solutions, rather than homogeneous pure substances, and to provide a guide to the vast literature on the experimental side of the subject. Pointing out that ferromagnetism as such is no longer a mystery, the author sees the need for providing the metallurgist with a magnetic approach to some of the most fundamental problems confronting him; namely, the preparation of materials of accurately known composition, the development of a theory of alloys, and the measuring of the internal strains and grain orientation of metals. Thus the book includes an introduction to the application of quantitative reasoning in metallurgy as well as a presentation of metallurgical problems to physicists. T. D. Yensen contributed the chapter on magnetic materials and their preparation; F. Zwicky, the appendix on cooperative phenomena; and W. C. Elmore, the sections on magnetic powders and their application to the study of magnetic structure.

Atomic Spectra and Atomic Structure. GERHARD HERZBERG, Research Professor of Physics, University of Saskatchewan. Tr. by J. W. T. Spinks, Assistant Professor of Chemistry, University of Saskatchewan. 271 p., 80 fig., 21 tables, 16×23 cm. *Prentice-Hall*, $4.25. This well-written book should prove most useful in an introductory course on atomic spectra or for any student who desires a general knowledge of the field. Stress is placed on experimental results and on their physical interpretation in terms of energy levels and the vector model of the atom. Long theoretical proofs are omitted, only the results and reference to original sources being given. After a short discussion of wave mechanics in general and the wave theory of the hydrogen atom in particular, further wave-mechanical interpretations are given throughout the book in fine print along with certain details which the author feels might be neglected in a first reading. These brief summaries of difficult theory are well done and constitute an important part of the book. From the mass of spectroscopic data available a careful selection of representative cases has been made for inclusion in the text; for example, energy-level diagrams are given and discussed for one element from each column of the periodic table and for a few special elements. All topics in atomic spectra with the exception of x-ray spectra are covered and, in the concluding chapter, applications of spectroscopic theory to paramagnetism, diamagnetism and the problem of the chemical properties of the elements are discussed.

Cambridge Physical Tracts. 14×22 cm. *Cambridge Univ. Press* and *Macmillan*, $1.75 per volume, paper cover. Issued under the general editorship of M. L. E. OLIPHANT AND J. A. RATCLIFFE, these tracts are intended to provide accounts of subjects which are advancing so rapidly that full-length books would be out of place. Each author is encouraged to present his subject primarily from the point of view of his own researches and in a manner similar to that he would employ in a short course of specialized lectures. The following three tracts are now available:

Negative Ions. H. S. W. MASSEY. 119 p., 19 fig., 7 tables. A survey of the present extent of knowledge concerning simple negative ions, with chapters on negative atomic ions, negative molecular ions, modes of formation of negative ions, detachment of electrons from negative ions, and negative ions in glow discharges and in the upper atmosphere. Free use is made of quantal interpretations and suggestions. Material involving elaborate mathematics is relegated to small type.

The Mobility of Positive Ions in Gases. A. M. TYNDALL. 103 p., 35 fig., 2 tables. Mainly a report of the important work in this field carried on in the H. H. Wills Physical Laboratory, Bristol. It consists of a historical introduction and chapters on methods of measurement, ion sources, theoretical aspects, effects of temperature, relation between mobility, field and pressure, effect of polar impurities, the nature of ions in air, and large ions.

Superconductivity. D. SHOENBERG, 122 p., 23 fig., 2 tables. Although written mainly from the point of view of the recent developments—which make it possible now to correlate some of the properties of superconductors and thus to distinguish between fundamental and secondary effects—this tract also provides a relatively comprehensive survey of superconductive phenomena in general. The bibliography of recent literature is extensive. Besides an introduction and summary, there are separate chapters on the magnetic properties of a perfect conductor and a superconductor, the intermediate state, the superconducting ring and disturbance of superconductivity by a current, the thermodynamics of superconductivity, and superconducting thin films.

MISCELLANEOUS BOOKS

Trains. ROBERT SELPH HENRY. Rev. ed. 110 p., 107 photographs, 22×30 cm. *Bobbs-Merrill*, $1.75. This revised and modernized nontechnical account of railroading and its history should appeal to many adults as well as to children. It is highly authentic and well written, and the many photographs are exceptionally well chosen and interesting.

Glossary of Physics. Compiled and edited by LEROY D. WELD, Professor of Physics, Coe College. 265 p., 14×21 cm. *McGraw-Hill*, $2.50. Some 3250 terms are described in this useful glossary. Although the definitions have deliberately been made brief, they are informative and accurate, and in many cases include references to books or articles giving lengthier discussions of the terms. The glossary is not intended to be a critical study or an exhaustive treatment of terminology but to provide a ready reference to actual usage that will be useful both to students and to specialists in the physical sciences. It should be available in every physics library. The compilation was carried out with the collaboration of a large group of physicists, and under the auspices of the Division of Physical Sciences of the National Research Council.

Sound Waves—Their Shape and Speed. Dayton Clarence Miller, Professor of Physics, Case School of Applied Science. 175 p., 64 fig., 6 plates, 5 tables, 14×21 cm. *Macmillan*, $2.75. This nontechnical but serious account deals in the first part with sound and tone quality, the phonodeik, shapes of sound waves, and electric-spark photography. The second part is a final report on several phases of the author's extensive researches conducted at the Sandy Hook Proving Ground, and includes material on pressure effects in the air near large guns, wave forms and propagation of sound from large guns, and the speed of sound in air. The illustrations are good and the bibliography quite comprehensive.

Practical and Theoretical Photography. Julian M. Blair, Associate Professor of Physics, University of Colorado. 246 p., 40 fig. and plates, 13×19 cm. *Pitman*, $2. Although planned originally for use as a text in an elementary college course in photography, this book should also be of interest to the general reader. The emphasis throughout the book is primarily on photography rather than on physical principles as they are illustrated by photography. The main topics and their order of appearance are as follows: cameras and developers, films, printing, enlarging, photography of colored objects, infra-red photography, desensitizers, portraits, x-rays, lenses, intensification, reduction, lantern slides, photomicrographs, natural color photography, coloring, toning, spotting and retouching, night photography, silhouettes, police and news photography, photoengraving from line subjects, stereoscopic pictures, composition, density, details of development, fixing, washing, silver halide crystals and the latent image. Most of the chapters include brief directions for experiments and a list of questions.

Fundamentals of Radio. Frederick Emmons Terman, Professor of Electrical Engineering, Stanford University. 466 p., 278 fig., 17 tables, 15×23 cm. *McGraw-Hill*, $3.75. Professor Terman now presents an abridged version of his well-known *Radio Engineering* that will serve as a text for an introductory radio engineering course. Although some of the more advanced theoretical developments and many details given in the larger book are omitted, the new text offers a clear exposition of the principles of radio communication and their applications. While the emphasis is placed on fundamental concepts and methods, a large amount of practical information on modern practice in radio design is also presented. Following the development of the theory and applications of vacuum tubes there are chapters on radio transmitters, radio receivers, propagation of radio waves, radio aids to navigation, television and acoustics which should be of interest to the general reader as well as to those primarily interested in radio engineering. Problems follow each chapter, nearly 400 in all, many of them good practical problems in radio design. Complex quantities are not used in this text.

Van Nostrand's Scientific Encyclopedia. 1234 p., 1500 figs., 18×26 cm. *Van Nostrand*, $10. More than 10,000 terms, arranged alphabetically and cross-indexed, are discussed in this one-volume encyclopedia of chemistry, physics, geology, mineralogy, astronomy, mathematics, botany, zoology, engineering, navigation, aeronautics, and medicine. For physics, Professor LeRoy D. Weld was the contributing editor, and Professors Erich Hausmann and Edgar P. Slack were the consulting editors. The articles vary in length from a few lines to more than a page, and the terms involved range from the most familiar to many that are highly specialized. In most of the articles the treatment is progressive, beginning with simple material and passing to more rigorous and detailed considerations. In the case of some of the more technical physical and engineering topics, this scheme for meeting the needs of both advanced students and beginners is only moderately successful, as is to be expected. To state briefly both the simple and the technical essence of an isolated scientific concept is not always possible and where it can be done, requires very skilful wording as well as a complete understanding of the concept. In scientific reliability and comprehensiveness, this encyclopedia is distinctly superior to the usual run of popular reference books and dictionaries; it represents a type of reference book on the sciences and their applications that has been needed badly. The printing and binding are good.

Exhibits

Aluminum Samples. *Aluminum Cooking Utensil Co.* (New Kensington, Pa.), gratis. Samples of crude and purified aluminum ore, and an ingot of aluminum.

Pamphlets and Catalogs

Industrial Insulation Catalog. *Eagle-Picher Sales Co.* (Temple Bar Bldg., Cincinnati), gratis to college teachers. Data and information on thermal insulation and related topics.

Comfort and Cleanliness in Your Home. *Holland Furnace Co.* (Holland, Mich.), gratis. Photographs and diagrams of warm-air furnaces.

Finch Electron Diffraction Camera. *W. Edwards & Co.* (Vaughan Road, Loughboro' Junction, London, S.E. 5), gratis. Specifications, diagram and a photograph of a standard electron diffraction camera and accessories.

A Lesson on the Transformer. Bull. 155. *Central Scientific Co.* (Chicago), gratis. Gives the theory and procedure for five elementary laboratory experiments that may be performed with the Cenco Model Transformer.

Notes on Fault Location in Cables. Note Book E-53-441. *Leeds & Northrup Co.* (4901 Stenton Ave., Philadelphia), gratis to college teachers. The electrical principles and many applications involved in the location of faults in conductors used for communication and power transmission.

Current Radio Reference—A Bibliography. Lawrence D. Batson. 61 p., 15×27 cm, mimeographed. *Electrical Div., Bureau of Foreign and Domestic Commerce* (Washington), gratis to institutions. A comprehensive list of books, periodicals, and government publications issued since 1933 on all phases of radio.

DIGEST OF PERIODICAL LITERATURE

Apparatus and Demonstrations

Experiments with a mirror of variable curvature. W. V. Burg; *Sch. Sci. and Math.* **38**, 968–70, Dec., 1938. The simple and inexpensive apparatus shown in Fig. 1 enables

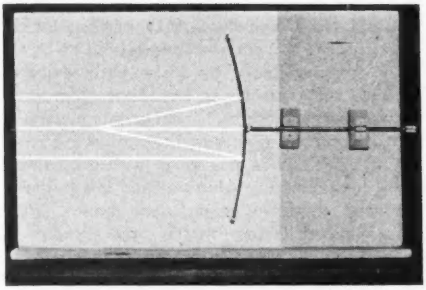

FIG. 1. Mirror of variable curvature.

the student to observe the gradual change in curvature of a mirror and the consequent change in its optical properties. The mirror—a highly polished, rectangular strip of flexible metal—is placed perpendicular to a wooden base covered with white paper, and so close to the latter that no light will pass behind the reflecting surface. The upper and lower edges of the mirror are held between small cylindrical tubes that are inserted in the board at right angles; two tiny pins, soldered to the mirror near the edges, just touch these tubes when the curvature has reached the limit for satisfactory reflection, this limit being the same whether the shape is convex or concave. The center of the mirror is supported by a horizontal guide rod. A small round plate on the left-hand end of this rod turns freely in a small case soldered to the back of the mirror. The rod is held parallel to the board by two metal guides mounted on small wooden blocks. The right-hand guide is a screw nut and the right-hand portion of the rod is provided with a fine screw-thread. A knob on this end of the rod facilitates turning it.—D. R.

Rules for Dropping Nonsignificant Figures

Proposed American recommended practice for rounding off decimal values. American Standards Association, Tentative report Z25.1, Jan., 1938. In calculations involving numbers expressed to several decimal places it is usually necessary to decide upon the number of places to be retained and to follow a definite rule in "rounding off." The rule usually followed is to keep unchanged the last figure retained when the first figure discarded is less than *5*, and to increase by *1* the last figure retained when the first figure discarded is more than *5*. There is diversity of practice when the first figure discarded is *5*. In such cases some computers "round up," that is, increase by *1*, the last figure retained; others "round down," that is, discard everything beyond the last figure retained. Obviously, if the retained value is always "rounded up," the sum and the average of a series of values so rounded will be too large; while if always "rounded down," the sum and the average of a series of rounded values will be too small.

Recommended rules. The committee recommends the following rules: (1) The figure in the last place to be retained should be kept unchanged (*a*) when the figure in the next place is less than *5*, (*b*) when the figure in the next place is *5* followed by no other figures or only by zeros, and the figure in the last place retained is even; (2) The figure in the last place to be retained should be increased by *1* (*a*) when the figure in the next place is more than *5*, (*b*) when the figure in the next place is *5* followed by no other figures or only by zeros, and the figure in the last place retained is odd, (*c*) when the figure in the next place is *5* followed by any figure or figures other than zero.

The final rounded value should be obtained from the most precise value available and not from a series of successive roundings. For example, 0.5499 should be rounded off successively to 0.550, 0.55 and 0.5 (not 0.6), since the most precise value available is less than 0.55. Similarly, 0.5501 should be rounded off as 0.550, 0.55 and 0.6, since the most precise value available is more than 0.55.

Places retained. Careful consideration should be given to the number of places to be retained, as well as to the method of "rounding off." In making conversions, for example, between inches and millimeters, sufficient places should be retained to avoid sacrifice of precision in the process of conversion and, at the same time, not so many places should be retained as to imply a precision that is not warranted or not necessary. In engineering and industrial work a good general rule to follow is: At each step in a calculation involving several steps, retain one more place than is required to maintain the precision represented by the least precise factor involved; the final value should be cut off at such a point that only the figure in the last place retained is in doubt. This rule is to be used only if the nature of the problem under consideration and experience with the method by which it should be solved show that the rule guarantees a sufficient degree of accuracy.—D. R.

A Survey of New Insulating Materials

Recent developments in electrical insulating materials. L. Hartshorn; *J. Sci. Inst.* **15**, 217–222, July, 1938. Recent developments have made available many new insulating materials. They are divided into three groups: (1) those for general experimentation; (2) those for high frequency work; and (3) liquids or fusible solids for impregnation or immersion mediums.

Instrument panel materials must possess high surface

and volume resistivity. New ebonite is excellent but rapidly deteriorates in light and in moist air unless protected by lacquer or a metal covering. By adding other ingredients to rubber and sulfur—the only constituents of pure ebonite—materials have been produced which, while slightly inferior in insulating properties to ebonite, show little deterioration upon exposure to light. To raise the softening-temperature of ebonite above 60° C various mineral fillers are added; but these "loaded ebonites" are difficult to machine and usually have inferior electrical properties, although ebonites loaded with silica have a low power factor.

The insulating parts of most commercial instruments are moulded in a "plastic" material of pure synthetic resins, finely divided wood, fabrics, or mica bonded with a resin. For sheets, rods or tubes, laminated materials consisting of sheets of paper or some textile material bonded with a synthetic resin, e.g., Bakelite, are competitors of ebonite. Although inferior in electrical properties they show little surface deterioration, are strong mechanically, and withstand temperatures exceeding 100°C. "Mycalex"—powdered mica bonded with borates of lead and sodium—is useful when permanence of linear dimensions and ability to withstand high temperatures are essential.

In high frequency work, two kinds of materials are needed: materials like quartz, with a low product of dielectric constant and power factor; and (2) materials like mica, with a high dielectric constant and low power factor. New materials of both kinds fall into two classes, synthetic resins and ceramics.

Hydrocarbon resins are valuable dielectrics. For example, polystyrene, $(C_6H_5 \cdot CH : CH_2)_n$, is a clear glass-like solid (sp. gr., 1.05) of very low dielectric constant (2.2–2.5) and a power factor sometimes as low as 2×10^{-4}. It softens at about 60°C without decomposition, is easily machined on the surface, but must be drilled slowly with water cooling. It dissolves in benzene and aromatic hydrocarbons, and the solution serves as a cement for joining two pieces together. Because of its high resistivity, polystyrene may rival amber for electrometer work although its stability cannot be taken for granted. Resins from acrylic acid derivatives and ketones, having greater mechanical strength but inferior electrical properties, are valuable for nonmetallic nuts, bolts and screws. Some of these resins are transparent, more flexible than ordinary glass, and in thin sheet form can be bent to any contour. Their chief disadvantage is a tendency to change with age.

Important ceramic materials belong to the steatite or the rutile groups. The steatite group, containing magnesium silicate, has a low power factor at high frequencies and is equivalent to mica in a form easy to handle; these materials, manufactured like ordinary ceramics, may be ground but not machined. The rutile group, containing a crystalline form of titanium dioxide mixed with suitable binders in various proportions, gives a series of ceramics with dielectric constants 20 to 100 and very low power factors at high frequencies; their principal use is in compact condensers for short wave work. Mixtures of a magnesium silicate material (with a negative temperature coefficient of dielectric constant) and a rutile material (with a positive coefficient) gave ceramics with a dielectric constant of about 10 and a negligible temperature coefficient. Titanium dioxide combined with an alkaline earth has a low power factor even at low frequencies. These ceramic materials may vary in quality and their properties usually change with the humidity. They may be used at temperatures up to 600°C.

Since films of metals like silver may be fused on to the surface of magnesium silicate ceramics, condensers may be made by fusing metal electrodes to a plate of the ceramic, thus insuring intimate and permanent contact. Likewise, films of metal in the form of coil-turns may be fused to surfaces of cylinders, disks, or rings for coils of fixed inductance. The metal thickness is built up by electroplating or spraying. Since the linear expansivity of the ceramic is low these coils have a low temperature coefficient and may serve as standards. These ceramic materials may be fused with certain glasses and the joints are gas-tight.

The search for liquids and waxes with good insulating properties, high dielectric constant, and low power factor has produced the chloronaphthalene waxes (dielectric constant, 5; power factor, $\sim$0.001) and the chlorinated diphenyls in various forms from viscous liquids to glassy solids (dielectric constant, 5; power factor, under suitable conditions, $<$0.01). These halogen derivatives of hydrocarbons excel the hydrocarbons in dielectric constant by a factor of 2 and are noninflammable.

Progress in the development of insulating materials will likely depend on research on the relations between dielectric properties, mechanical properties, physical structure, and chemical structure. A material with good dielectric properties and a magnetic permeability greater than unity would have important applications in the construction of induction coils. A table of data on the properties of insulating materials is included in the article.—H. N. O.

Check List of Periodical Literature

Contributions of engineering to physics. M. L. E. Oliphant; *Engr.* **166**, 319–20, Sept. 16, 1938. An address before the British Association.

What is gravitation? P. Heyl; *Sci. Mo.* **47**, 114–23, Aug., 1938. Review past and present knowledge of gravitation.

It is called electricity. W. R. Whitney; *J. Frank. Inst.* **226**, 399–411, Sept., 1938. A nontechnical discussion of the nature of electricity.

Exploration by balloon. J. Piccard; *Sci. Mo.* **47**, 270–77, Sept., 1938.

The shape and size of the earth. W. Bowie; *Sci. Mo.* **47**, 506–10, Dec., 1938. A brief survey of present knowledge of the earth's figure.

Science and society in ancient Rome. W. Salant; *Sci. Mo.* **47**, 525–35, Dec., 1938. Science in truth has its roots in society, but to assert that the economic factor alone accounts for the existence and progress of science is an oversimplification and leads to erroneous conclusions.

Preparation of college teachers. H. L. Dodge; *J. Eng. Ed.* **29**, 62–72, Sept., 1938. A survey of current opinions.

Photography and the advance of pure science. C. E. K. Mees; *J. Frank. Inst.* **226**, 281–92, Sept., 1938.